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Cyclopedia
of
Engineering

A General Reference Work on

STEAM BOILERS AND PUMPS; STEAM, STATIONARY, LOCOMOTIVE, AND MARINE
ENGINES; STEAM TURBINES; GAS AND OIL ENGINES; GAS-PRODUCERS;
COMPRESSED AIR; REFRIGERATION; ELEVATORS; HEATING
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Grateful acknowledgment is made here also for the invaluable co-operation of the foremost engineering firms in making these volumes thoroughly representative of the best and latest practice in the design and construction of steam and electrical machines; also for the valuable drawings and data, suggestions, criticisms, and other courtesies.

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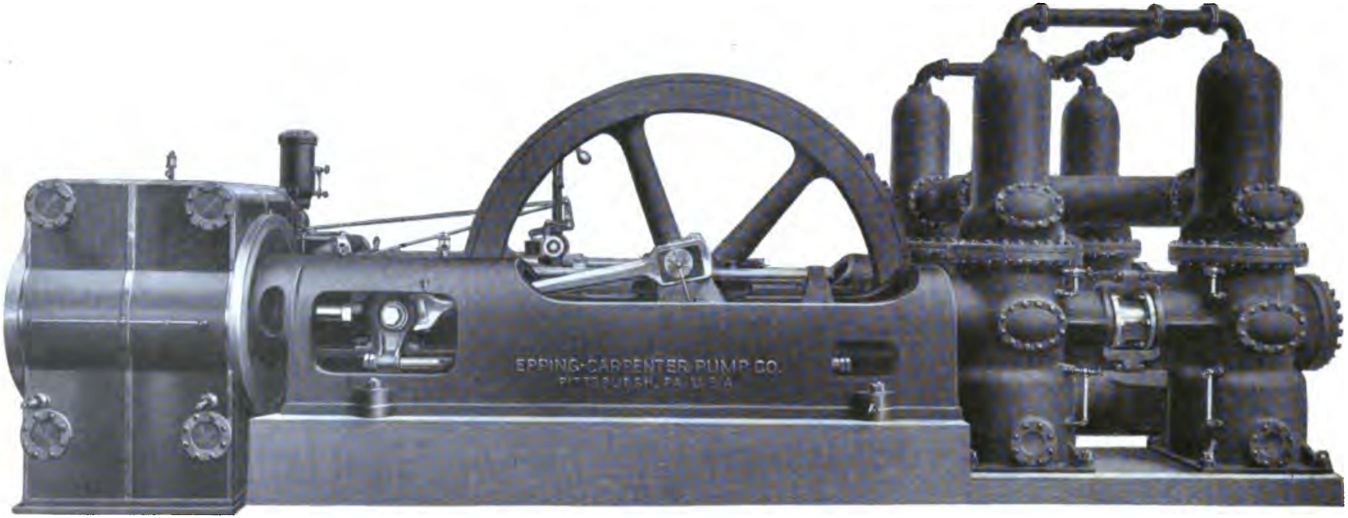

COMPOUND CORLISS TYPE STEAM PUMP
Courtesy of Epping-Carpenter Company

Foreword

THE "prime mover", whether it be a massive, majestic Corliss, a rapidly rotating steam turbine, or an iron "greyhound" drawing the Limited, is a work of mechanical art which commands the admiration of everyone. And yet, the complicated mechanisms are so efficiently designed and everything works so noiselessly, that we lose sight of the wonderful theoretical and mechanical development which was necessary to bring these machines to their present state of perfection. Notwithstanding the genius of Watt, which was so great that his basic conception of the steam engine and many of his inventions in connection with it exist today practically as he gave them to the world over a hundred years ago, yet the mechanics of his time could not build engine cylinders nearer true than three-eighths of an inch — the error in the modern engine cylinders must not be greater than two-thousandths of an inch.

¶ But the developments did not stop with Watt. The little refinements brought about by the careful study of the theory of the heat engine; the reduction in heat losses; the use of superheated steam; the idea of compound expansion; the development of the Stephenson and Walschaert valve gears — all have contributed toward making the steam engine almost mechanically perfect and as efficient as is inherently possible.

¶ The development of the steam turbine within recent years has opened up a new field of engineering, and the adoption of this form of prime mover in so many stationary plants like the immense Fisk Station of the Commonwealth Edison Company, as well as its use on the gigantic ocean liners like the Lusitania, makes this angle of steam engineering of especial interest.

¶ Adding to this the wonderful advance in the gas engine field — not only in the automobile type where requirements of lightness, speed, and reliability under trying conditions have developed a most perfect mechanism, but in the stationary type which has so many fields of application in competition with its steam-driven brother as well as in fields where the latter can not be of service — you have a brief survey of the almost unprecedented development in this most fascinating branch of Engineering.

¶ This story has been developed in these volumes from the historical standpoint and along sound theoretical and practical lines. It is absorbingly interesting and instructive to the stationary engineer and also to all who wish to follow modern engineering development. The formulas of higher mathematics have been avoided as far as possible, and every care has been exercised to elucidate the text by abundant and appropriate illustrations.

¶ The Cyclopedia has been compiled with the idea of making it a work thoroughly technical, yet easily comprehendible by the man who has but little time in which to acquaint himself with the fundamental branches of practical engineering. If, therefore, it should benefit any of the large number of workers who need, yet lack, technical training, the publishers will feel that its mission has been accomplished.

¶ Grateful acknowledgment is due the corps of authors and collaborators — engineers and designers of wide practical experience, and teachers of well-recognized ability — without whose co-operation this work would have been impossible.

Table of Contents

VOLUME I

CONSTRUCTION OF BOILERS . . . .
. . . By W. S. Newell; Revised by R. H. Kuss† Page* 11

Boiler Materials—Physical Tests—Testing Machines—Rules for Testing Boiler Steel—Boiler Manufacturing Processes—Riveted Joints—Types of Riveted Joints—Calking—Welded Joints—Arrangements of Plates and Joints—Manholes—Stays—Boiler Tubes and Flues—Boiler Requirements—Boiler Horsepower—Area of Grate—Steam Space—Heating Surface—Allowable Pressure—Furnace Flues—Boiler Inspection During Manufacture

TYPES OF BOILERS . . . . . Revised by R. H. Kuss Page 71

Classification—Early Forms—Modern Flue: Cornish, Lancashire, Galloway—Fire-Tube: Common Horizontal, Vertical, Internally-Fired Marine Type (Return-Tubular, Through-Tube), Fire-Box (Locomotive, Stationary), Peculiar Forms (Cochrane, Shapley, Brady, Directurn)—Water-Tube: Babcock and Wilcox, Worthington, Edge Moor, Heine, Mosher, Thornycroft-Marshall, Niclausse, Wickes, Cahall, Stirling, Rust, Bigelow-Hornsby, Connelly, Erie City, Hazelton, Harrison—Marine Boiler Types: Rectangular, Cylindrical, Water-Tube (Babcock and Wilcox, Standard, Almy)—Boiler Design: Features of Individual Boilers (Circulation, Accessibility, Shapes and Sizes of Tubes) Plant Features Influencing Boiler Design

BOILER ACCESSORIES . . . .
. . . . By W. S. Leland; Revised by R. H. Kuss Page 169

Boiler Attachments: Manholes and Handholes, Supports, Fusible Plugs, Steam Gages, Water Columns, Valves, Steam Piping—Water-End Auxiliaries: Feed-Water Requirements, Pumps, Regulating and Heating Feed Water—Steam-End Auxiliaries: Superheaters, Steam Separators, Traps, Soot Blowers, Lagging—Draft Apparatus—Fuel Economizers—Power Plant Accessories: Coal Handling, Ash Handling

BOILER PRACTICE . By W. S. Leland; Revised by R. H. Kuss Page 257

Heat Generation: Boiler Settings (Supporting Structures, Hand-Fired Furnaces, Hand-Fired Grates), Firing by Hand (Special Hand-Fired Furnaces, Oil-Burning Furnaces), Mechanical Stokers (Types, Manipulation of Special Furnaces and Mechanical Stokers, Operating Combinations of Units, Boiler Room Measuring Instruments)—Care of Boilers: Management, External and Internal Corrosion, Scale Formation, Boiler Explosions, Smoke Prevention—Fuels and Fuel Economy: Heat Value of Fuel, Boiler Trials

PUMPS . . . . By A. L. Rice Page 367

Principles of Action—Jet—Rotary—Centrifugal—Reciprocating—Valves (Flexible, Hinged, Poppet, Ball)—Design and Construction—Single—Duplex—Triplex—Direct Acting—Belt Driven—Motor Driven—Combined Condenser—Compressed Air—Automatic Control—Steam Valves—Erection—Piping—Care—Testing

REVIEW QUESTIONS . . . . Page 481
INDEX . . . . Page 493

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* For page numbers, see foot of pages.

† For professional standing of authors, see list of Authors and Collaborators at front of volume.

VIEW OF BOILER FACTORY OF SAMUEL SMITH AND SONS COMPANY, PATERSON, NEW JERSEY

CONSTRUCTION OF BOILERS

INTRODUCTION

Essential Principles of Boiler Action. A steam boiler is a closed vessel used for generating steam from water by the application of heat. The boiler part of the steam-generating equipment must be clearly distinguished from the part having to do with the generation of the heat which is offered to the boiler for absorption. The place or space in which heat is liberated from fuel by fire is called the furnace, and, while closely associated with the art of steam generation, does not, in this paper, form an essential part of the subject under treatment. However, boiler construction is influenced to a considerable degree by the conditions imposed by highly heated gases coming into contact with boiler materials, and to this degree reference will be made to construction modifications to allow for expansion, pressure, etc.

In actual practice boilers are only partly filled with water, the remaining portion of the interior being filled with steam. Moreover, facilities must be provided for supplying water to replace that which evaporates into steam; for the proper control and delivery of the steam generated; for the safe operation of the boiler by the aid of easy and reliable means for determining the height of the water therein; for the automatic release of steam to prevent excessive pressure; and for the removal of accumulated mud and other impurities in the water without disturbing the continuity of operation. The devices used to perform the services mentioned are considered at length in the Instruction Paper entitled "Boiler Accessories", while the related topics of boiler operation, furnace economy and control, etc., are explained in "Boiler Practice".

Scope of Work. The intention, then, of this paper is to present an explanation of the characteristics of boiler construction without any attempt to meet conditions imposed by special branches of steam-generating service, as, for instance, locomotive practice, the thought being that the principles of construction, if worthy, must under all circumstances be preserved.

In accordance with this intention, three elements of prime importance will be considered; namely, *materials*, *designs*, and *workmanship*. It must be understood that these elements are closely associated. To illustrate, there are many designs which, because of the excellent materials and workmanship, are serviceable and reliable, but which with inferior material and workmanship would not be safe construction. Likewise, it is feasible and right to use certain kinds of materials in certain places and parts to which they are adapted, but which are not to be considered in other places and parts.

Finally, it is not possible to lay down a course of boiler construction which could be universally adopted; the design must be modified and adjusted to meet the facilities of the shop in which the boiler is made.

BOILER MATERIALS

PROPERTIES OF METALS

The materials of which boilers are constructed are exposed to conditions which weaken them and thus shorten the life of the boiler. Among these conditions are corrosion, both external and internal, high pressure, and expansion and contraction, due to varying temperatures and pressures.

Cast Iron. Cast iron was the material of which the earliest forms of boilers were made but, on account of its low tensile strength and unreliable nature, it is now but little used, except for small parts of water-tube boilers, and sometimes for the ends of low-pressure cylindrical boilers, and for fittings. It resists corrosion but, on account of its unreliability and brittleness, the parts must be made thick and therefore heavy.

Wrought Iron. Wrought iron, as late as 1870, was the principal material used for boiler plates. It is a pure iron prepared from pig iron by a process called puddling, described in "Metallurgy". Wrought iron is well adapted for use in boiler construction, as it is strong, tough, and fibrous, and combines high tensile strength with ductility and freedom from brittleness. When the properties mentioned are well combined, wrought iron will resist stresses due to unequal expansion. Boiler fastenings, stays, and other parts made

TABLE I

Specifications for Chemical Composition of Open-Hearth Steel

ELEMENT	FLANGE STEEL	FIRE-BOX STEEL	BOILER-RIVET STEEL
Manganese, per cent	0.30 to 0.60	0.30 to 0.50	0.30 to 0.50
Phosphorus, per cent Basic	0.04	0.035	0.04
Phosphorus, per cent Acid	0.05	0.04	0.04
Sulphur, maximum per cent	0.05	0.04	0.045

by welding are sometimes made of wrought iron. It is customary to consider that a bar loses about one-quarter of its strength by welding, although it is often stronger in the weld, owing to the working of the metal during the welding process.

Steel. Steel has entirely displaced iron for boiler-shell work. Boiler steel is made by the open-hearth process, and contains for ordinary thicknesses of 1 or 1¼ inches 0.25 per cent carbon, while thinner plates of ¼ inch should not contain over 0.15 per cent carbon. Larger percentages of carbon, while accompanied by an increase in tensile strength, lessen the ductility. The following properties show steel to be the best boiler material at present: great tensile strength, ductility, homogeneity, toughness, freedom from blisters and internal unsoundness. Blisters and unsoundness are faults sometimes met with in wrought-iron plates.

Chemical Composition. Open-hearth steel comes in three grades suitable for boiler use; viz, flange, fire-box, and boiler-rivet. It is customary to stipulate the requirements as to chemical composition, as in Table I.

The percentages given show that a very small amount of the steel is made up of matter other than iron; these small amounts, however, have a striking influence on the relative ductility, toughness, and tensile strength of the steel.

To determine whether the boiler material conforms to any requirement such as given, a chemical analysis must be made.

All steel ingots coming from the same ladle, as prepared by the open-hearth process, are not of uniform or homogeneous structure, different parts of the ladle producing steel of the three different grades mentioned. The position of the several grades of steel in the ladle is, of course, known by experiment and experience, and, as will be explained hereafter, there is no sharp line of demarcation between flange steel and fire-box steel, or between fire-box steel and boiler-rivet steel.

Copper. Copper in many respects is superior to wrought iron for boiler construction. It is homogeneous, resists oxidation (the corrosive action of most feed waters), and incrustation. It is more ductile and malleable, and is a better conductor of heat, which not only gives it a higher evaporative usefulness, but also enables it to last longer under the intense heat of the furnace. Its disadvantages are its low tensile strength (about 30,000 pounds per square inch) and its decrease of strength with an increase of temperature. In heating from the freezing point to the boiling point it loses 5 per cent of its strength, and at 550 degrees F. it has lost about one-quarter of its strength at freezing point. For these reasons, and on account of its high price, it is now seldom used in boiler work except in very special places.

Brass. Brass is an alloy of copper and zinc in which the proportions vary considerably. Red brass is better and more expensive than yellow brass as it contains a larger percentage of copper. Brass is used for valves, gages, and other fittings. Internal feed and other piping is preferably made of brass, as it resists corrosion and can be kept free of scale incrustation.

Bronze. Bronze is an alloy of copper and tin, and is advantageously used for valves and seats of valves where the wear is great.

PHYSICAL TESTS

In order to determine the strength and other qualities of the materials, specimens are tested, the results showing the ultimate tensile strength, elastic limit, contraction of area, and elongation. These quantities as well as the rules and terms used in the text may be the better understood by a careful study of the following definitions.

Definitions. *Stress.* The number of pounds of force applied per square inch is called the stress. If the piece is under direct tension or compression, the stress is considered uniformly distributed and is equal to the load divided by the area of the transverse section. Thus, if the section of the plate is 1″ by $\frac{7}{16}$″ and the actual stress is 17,750 pounds, the stress per square inch is

$$\frac{40{,}570}{.4375} = 17{,}750 \text{ lb. (approx.)}$$

Ultimate Strength. The maximum stress a test piece will stand per square inch is called its ultimate strength. For ductile materials the breaking stress is considerably less than the ultimate strength. That is, when the loads are gradually applied the total load will reach a maximum, and then the metal stretches so that at the moment of rupture the load is much less than the maximum. The strength of iron and steel depends somewhat upon the rate at which the load is applied; the more rapid the application the higher the stress as recorded by the scale beam.

Strain. Strain is the stretch per unit of length of the test piece when in tension. If the original length is L, and the stretch or elongation is B, the strain becomes

$$\frac{L}{B} = b$$

Elastic Limit. When testing a piece, at first the stress and strain are proportional. The point at which the strain or stretch begins to increase more rapidly than the stress is called the elastic limit. This limit is not definite; it can be determined approximately only. A load greater than the elastic limit will produce a permanent elongation.

Stretch Limit. The stretch limit is the stress at which the scale beam of the testing machine will fall while the straining head is at rest.

Reduction of Area. When a test piece ruptures, the area at that point is much less than the plate or bar before testing. This reduction shows the ductility of the material; it also shows the property of changing shape without actual rupture. This is important in boiler construction.

Elongation. Ductile materials stretch before breaking. To measure the ultimate elongation, the two broken pieces are placed in a straight line with the broken ends in contact and the length between points is then measured. As the prick punch marks are made before testing, the elongation is easily determined. The ratio of the elongation to the original length is called the ultimate elongation. Suppose the distance between the extreme prick punch marks is 8 inches before testing and $9\frac{7}{8}$ inches after. Then the bar or plate has stretched $1\frac{7}{8}$ inches. The ultimate elongation is $1\frac{7}{8} \div 8$, or .234, or 23.4 per cent.

Diagrams. These various properties of materials may be shown by diagrams. Fig. 1 shows the diagram for wrought iron and steel when under tension. The unit stresses are taken as ordinates and the unit elongations as abscissas. For each stress the corresponding elongation, as found by the testing machine, is laid off. The curve is drawn through these points. Each specimen has its own curve, those shown in Fig. 1 being plotted from average values. Since stress and elongation are proportional up to the elastic limit, the curve from the origin to the elastic limit is a straight line. At the elastic limit the curve changes suddenly and the elongation increases rapidly. From the elastic limit to the point at which the piece breaks the stress is not proportional to elongation. The end of the curve indicates the point of rupture. Curves show the properties of various materials. It is seen that the elastic limit is not well defined but can be estimated very nearly. These curves may be plotted from results of tests or they may be drawn automatically by the testing machine.

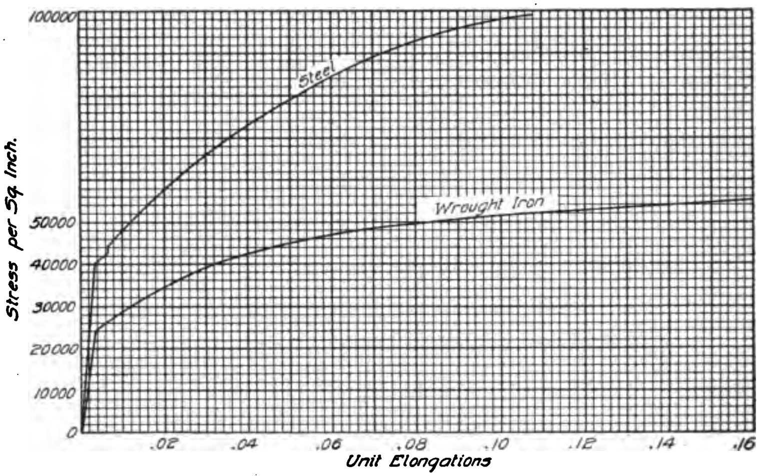


Fig. 1 Curves Showing Elongation of Steel and Wrought Iron Under Various Stresses

Testing Machines. The simplest way to test a piece of iron bar or plate for tensile strength would be to suspend a bar vertically, fixing it firmly at the upper end and hanging weights on the other end until the bar is broken. This is a crude method, and in order that the elastic limit and elongation may be determined at the same time, testing machines are used. There are many kinds of testing machines, adapted for various materials, but the general principles are the same.

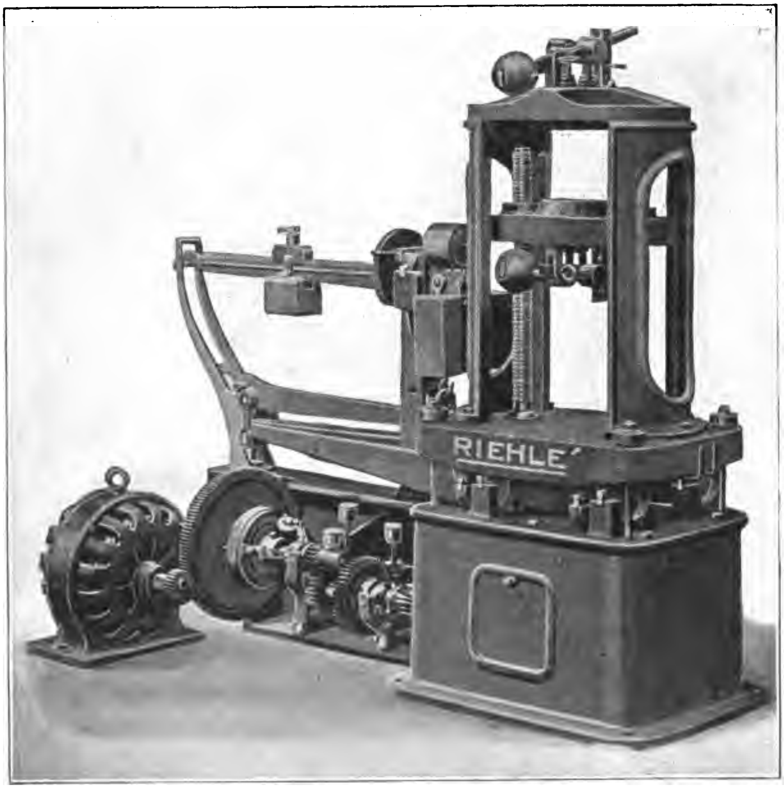


Fig. 2. Standard Testing Machine
Riehle Brothers Testing Machine Company, Philadelphia

The testing machine consists of a frame and two heads, to which the ends of the test piece are fastened by wedges or other devices. By means of steam or hydraulic power one head is drawn away from the other for tensile tests. The pull is transmitted to a weighing device, usually levers and knife edges like the beam of an ordinary platform scale. In small machines the pull may be applied by a lever.

Testing machines are made for all varieties of testing: tensile, compressive, and shearing strength; also for deflection of beams, and for strength of wood, cement, brick, and stone. Fig. 2 shows a Riehle testing machine designed for tensile and compressive tests of iron and steel.

Standard Testing Regulations. While the principles of testing materials are simple it is essential that the methods of applying them be uniform and as practiced by engineers, so that the results may be comparable. For this reason regulations supported by engineering societies have been enacted, not by legislation necessarily, but by the societies or boards themselves. These regulations have all the force of legislative enactments since they are observed by persons dealing with the subject.

The essential features of all the rules pertaining to boiler steel and the testing of it are contained in the following rules which are essentially those of the American Society of Mechanical Engineers. For the complete list of rules, see those prepared by the Society and found in all engineering libraries.

RULES FOR TESTING BOILER STEEL

SECTION 1

BOILER SHELL MATERIAL

1. All materials used in the construction of boilers shall conform to the specifications hereunder given.

2. Only the best quality of open-hearth steel shall be used.

CHEMICAL COMPOSITION

3. All steel shall conform to the following requirements as to chemical composition:

(*a*) Chemical Limits: manganese, 0.30 to 0.50 per cent; phosphorus, 0.03 per cent maximum; sulphur, 0.03 per cent maximum.

(*b*) Analysis: To determine whether the material conforms to the requirements specified, an analysis shall be made by the manufacturer from a test ingot taken during the pouring of each melt. A copy of this analysis shall be given, upon request, to the purchaser or his representative.

(*c*) Check Analysis: A check analysis may be made by the purchaser at his own expense, from one or more broken tension-test specimens as selected by the inspector. Samples to be taken for check analysis, in the case of plates, by drilling through the entire thickness of the material, and in the case of bars by drilling or turning in such manner as to secure the sample to represent, as nearly as possible, the material lying midway between the central axis and the outside of the bar, care being taken to remove all scale, rust, grease, etc., so that no foreign matter shall be in the sample. This analysis shall conform to the requirement specified.

PHYSICAL PROPERTIES AND TESTS

4. *Physical Properties.* All bar steel and all shell plates and butt straps, which in service will be subject to full tension stress and used in pressure vessels not subject to the direct action of the fire or products of combustion, shall show physical properties as follows:

(I) PHYSICAL PROPERTIES REQUIRED FOR BAR STEEL AND STEEL PLATES

Tensile strength, per sq. in.	55,000 to 65,000 lb.
Elongation in standard 8-in. specimen	not less than 23 per cent
Reduction of area	not less than 50 per cent

It is very desirable that all plates 1 inch and over in thickness intended for shell plates of boilers shall be annealed at the plate mill.

(II) PHYSICAL PROPERTIES REQUIRED FOR STEEL PLATES EXPOSED TO FIRE OR PRODUCTS OF COMBUSTION

Tensile strength, per sq. in.	52,000 to 60,000 lb.
Elongation in standard 8-in. specimen	not less than 25 per cent
Reduction of area	not less than 52.5 per cent

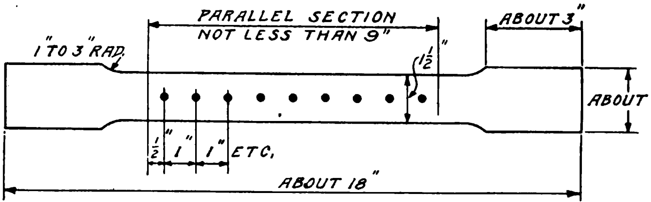
All bars for rivets, stay bolts, and braces, and all steel which is to be welded for furnaces, tubes, and pipes entering into the construction of boilers or other pressure vessels, shall show physical properties as follows, and shall be known as extra soft steel.

(III) PHYSICAL PROPERTIES REQUIRED FOR RIVETS, BRACES, TUBES, AND STEEL TO BE WELDED

Tensile strength, per sq. in.	45,000 to 55,000 lb.
Elongation in standard 8-in. specimen	not less than 28 per cent
Reduction of area	not less than 55 per cent

5. *Homogeneity Tests.* A sample taken from a broken tension-test specimen shall not show any single seam or cavity more than $\frac{1}{4}$ inch long, in either of the three fractures obtained in the test for homogeneity, which shall be made as follows:

A portion of the broken tension-test specimen is either nicked with a chisel or grooved on a machine, transversely, about $\frac{1}{16}$ inch deep, in three places about 2 inches apart. The first groove is made on one side, 2 inches from the square end of the specimen; the second, 2 inches from it on the opposite side; and the third, 2 inches from the last, on the opposite side from it. The specimen is then put in a vise, with the first groove about $\frac{1}{4}$ inch above the jaws, care being taken to hold it firmly. The projecting end of the test specimen is then broken off with a number of light blows of a hammer, the bending being away from the groove. The specimen is broken at the other two grooves in the same manner. The object of this test is to open and render visible to the eye any seams due to failure to weld up or to interpose foreign matter, or any cavities due to gas bubbles in the ingot. After rupture, one side of each fracture is examined, a pocket lens being used if necessary, and the lengths of the seams and cavities are determined.



PIECE TO BE OF SAME THICKNESS AS THE PLATE

Fig. 3. Steel Specimen for Tension Test

6. *Bend Tests.*

(*a*) Cold-bend tests shall be made on the material as rolled.

(*b*) Quench-bend test specimens, before bending, shall be heated to a light cherry red as seen in the dark (about 1200 degrees F.), and quenched in water, the temperature of which is about 80 degrees F.

(*c*) Specimens for cold-bend and quench-bend tests from plates shall bend through 180 degrees without fracture on the outside of the bent portion, as follows: For material 1 inch and under in thickness, flat on itself; for material over 1 inch in thickness, around a pin, the diameter of which is equal to the thickness of the specimen.

(*d*) Specimens for cold-bend and quench-bend test of boiler-rivet steel shall bend cold through 180 degrees flat on themselves without fracture on the outside of the bent portion.

(*e*) Bend tests may be made by pressure or by blows.

7. *Test Specimens.*

(*a*) Tension- and bend-test specimens for plates and brace bars, flat or square, shall be taken from the finished product, and shall be of the full thickness of material as rolled. Tension-test specimens shall be of the form and dimensions shown in Fig. 3. Bend-test specimens shall be 1½ inches to 2½ inches wide, and shall have the sheared edges milled or planed.

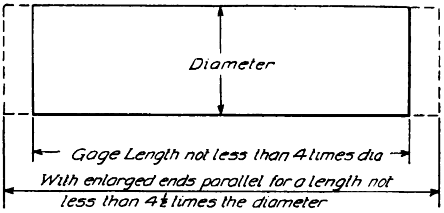

Diameter
Gage Length not less than 4 times dia
With enlarged ends parallel for a length not less than 4½ times the diameter

Fig. 4. Standard Test Piece for Rivets

(*b*) For tension tests, rivets will be tested to a gage length of not less than four times the diameter, as shown in Fig. 4.

Rivets from each lot offered, selected by the inspector, shall stand the following tests:

(1) *Bend Tests.* The rivet shanks shall bend cold through 180 degrees flat on themselves, as shown in Fig. 5, without fracture on the outside of the bent portion.

(2) *Flattening Tests.* The rivet heads shall flatten, while hot, to a diameter 2½ times the diameter of the shank, as shown in Fig. 6, without cracking at the edges.

(3) *Finish.* Rivets shall be true to form, concentric, and free from injurious scale, fins, seams, and other defects.

(4) *Rejection.* Rivets which fail to meet the requirements specified in (1) and (2) will be rejected and returned to the manufacturer, who shall pay return freight.

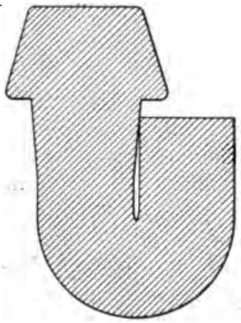


Fig. 5. Section of Rivet Shank After Bend Test

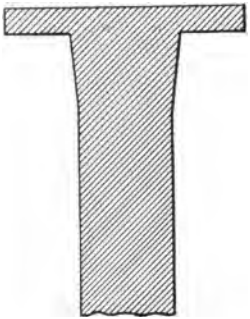


Fig. 6. Rivet Section After Flattening Test

FINISH AND MARKINGS

8. *Variation in Gage.* The thickness of each sheared plate shall not vary more than 0.01 inch under that ordered.

9. The finished material shall be free from injurious defects, and shall have a workmanlike finish.

10. All plates and other materials used in the construction of steam boilers and other pressure vessels shall be tested at the mill or place where such materials are manufactured, and the manufacturer shall make all tests and furnish such records of same as shall be required by these rules, and stamp each plate with the name of such manufacturer, where manufactured, and the heat number from which such plates were made, the tensile strength, and the thickness. Four such stamps shall be placed on each plate having an area of 25 square feet or under, about 6 inches from the edges at diagonal corners, and one about the center of the plate, or as may be directed by the inspector, as designated by the boiler maker in his order for the plates. Plates over 25 square feet area, shall have five such stamps, about 12 inches from the edge at the four corners, and one about the middle of the plate.

Each head or plate to be flanged shall be distinctly stamped by the manufacturers on both sides as directed by the purchaser of the material, or by the boiler maker, with the name of the manufacturers, place where manufactured, lowest tensile strength, and the thickness; stamps to be so located as to be plainly visible when the head is finished and in position in boiler or pressure vessel.

11. *Inspection and Rejection.*

(*a*) The inspector shall have free entry, at all times while work is being performed, to all parts of the manufacturer's works which concern the manufacture of the material ordered for boilers or other pressure vessels. The manufacturer shall afford the inspector, free of cost, all reasonable facilities to satisfy him that the material is being furnished in accordance with these specifications. All tests and inspections shall be made at the place of manufacture prior to shipment.

(*b*) Material which, subsequent to the above tests at the mills and its acceptance there, develops weak spots, brittleness, cracks, or other imperfections, or is found to have injurious defects, may be rejected at the shop, and shall then be replaced by the manufacturer at his own cost.

SECTION 2

MISCELLANEOUS MATERIAL

1. Shells, drums, butt straps, heads, combustion chambers, furnaces, or any plates that require staying or flanging, shall be of open-hearth steel as specified in Section 1, Paragraphs 2, 3, 4, 5, and 6, of these rules.

2. Tubes shall be made of seamless hot or cold drawn steel for water-tube boilers. Lap-welded steel tubes shall not be further used in new water-tube boilers nor in retubing old water-tube boilers.

3. Rivets, stay bolts, and braces shall be of open-hearth extra soft steel, as specified in these rules.

4. Cast steel for use in boilers and steam superheater mountings, manhole frames, steam pipe, fittings, side lugs, or any other parts of boilers or superheaters where cast steel is used, shall have the following chemical and physical properties:

(*a*) Chemical Composition: The steel shall conform to the following requirements as to chemical composition:

Phosphorus....................not over 0.05 per cent
Sulphur........................not over 0.05 per cent

(*b*) Chemical Analyses: To determine whether the material conforms to the requirements as to chemical composition specified in (*a*), an analysis shall be made by the manufacturer from a test ingot taken during the pouring of each melt. Drillings for analysis shall be taken not less than ¼ inch beneath the surface of the test ingot. A copy of this analysis shall be given to the purchaser or his representative.

A check analysis of castings may be made by the purchaser from a broken tension or bend-test specimen, in which case an excess of 20 per cent above the requirements as to phosphorus and sulphur specified in (*a*) will be allowed. If the specimen has been annealed, the drillings for analysis shall be taken not less than ¼ inch beneath the surface.

(*c*) Tension Tests: The steel for castings shall conform to the following minimum requirements as to tensile properties:

Tensile strength, lb. per sq. in.	50,000 to 60,000
Elongation in 2 in.	22 per cent
Reduction of area	30 per cent

(*d*) Bend Tests: The test specimen shall bend cold through 120 degrees for soft castings and 90 degrees for medium castings, around a 1-inch pin, without fracture on the outside of the bent portion. Bend tests may be made by pressure or by blows.

(*e*) Alternative Tests to Destruction: In the case of small or unimportant castings, a test to destruction on three castings from a lot may be substituted for the tension and bend tests. This test shall show the material to be ductile, free from injurious defects, and suitable for the purpose intended. A lot shall consist of all castings from the same melt, annealed in the same furnace charge.

(*f*) Test Specimens: Test bars shall be attached to all castings weighing 500 pounds or over, provided the design of the castings will permit. If the castings weigh less than 500 pounds or are of such a nature that test bars cannot be attached, two test bars shall be cast to represent each melt; or the quality of the castings shall be determined by tests to destruction as specified in (*e*). All test bars shall be annealed with the castings they represent. The manufacturer and purchaser shall agree whether test bars can be attached to castings, and also on the location of the bars on the castings and the method of casting unattached bars. Bend-test specimens shall be 1 by ½ inch in section.

(*g*) Number of Tests: One tension and one bend test shall be made from each melt. If any test specimen shows defective machining or develops flaws, or if a tension-test specimen breaks outside the gage length, it may be discarded; and the manufacturer and the purchaser or his representative shall agree upon the selection of another specimen in its stead.

5. Cast iron for use in boiler mountings, steam-pipe fittings, side lugs, or any other parts of boilers where cast iron is permitted to be used, shall not have less than 20,000 pounds tensile strength.

6. Cross pipes connecting the steam and water drums of water-tube boilers and cross boxes shall be of wrought or cast steel when the working pressure exceeds 125 pounds per square inch.

7. Mud drums of water-tube boilers and all pressure parts over 2-inch pipe size, or equivalent cross-sectional area, on any boiler, shall be of wrought or cast steel when the working pressure allowed on the boiler exceeds 125 pounds gage per square inch.

8. Pressure parts of superheaters, attached to boilers or separately fired, shall be of wrought or cast steel.

9. Boiler and superheater mountings, such as nozzles, cross pipes, steam pipes, fittings, valves and their bonnets shall be of wrought or cast steel when exposed to steam which is superheated over 80 degrees F.

10. Water-leg and door-frame rings of vertical fire-tube boilers, 36 inches or over in diameter, shall be of wrought or cast steel, or wrought iron. A wrought-

iron mud ring shall be used at the bottom in water legs of boilers, and this water leg shall not be formed by bending in the plates and riveting together at the edges.

11. Water-leg and door-frame rings of locomotive type boilers shall be of wrought or cast steel, or wrought iron.

SECTION 3

STAMPING OF BOILERS

1. In laying out shell plates, furnace sheets, and heads in the boiler shop, care shall be taken to leave at least one of the stamps, specified in Section 1, Par. 10, of these rules, so located as to be plainly visible when the boiler is completed; except that the tube sheets of a vertical fire-tube boiler shall have a portion, at least, of such stamps visible sufficient for identification when the boiler is completed.

2. Each boiler shall conform in every detail with these standard rules, and shall be distinctly stamped by a member of the state boiler department, or an inspector holding a certificate of competency as an inspector of steam boilers, and who is not, directly or indirectly, interested in the manufacture or sale of steam boilers, but in the employ of an insurance company authorized to insure boilers in this State. Each boiler shall be stamped by the builder, in the presence of the inspector, with a serial number and with the name of the builder either in full or abbreviated and the builder shall submit a facsimile of his proposed style of stamping to the state boiler department for approval. The height of letters and figures used in stamping shall not be less than ¼ inch.

3. In numbering serially, each builder shall commence with the number 1 and continue numbering in consecutive order.

4. *Location of Stamps.* The location of stamps is to be as follows:

(*a*) On horizontal return-tubular boilers—on the front head, above the central rows of tubes.

(*b*) On horizontal flue boilers—on the front head, above the flues.

(*c*) On locomotive type or star water-tube boilers—on the furnace end, above the handhole.

(*d*) On vertical fire-tube and vertical submerged-tube boilers—on the shell, above the furnace door.

(*e*) On water-tube boilers, Babcock and Wilcox, Stirling, Heine, and Robb-Mumford standard types—on a head above the manhole opening, preferably on the flanging of the manhole opening.

(*f*) On vertical boilers, Climax or Hazleton type—on the top head.

(*g*) On Cahall or Wickes vertical water-tube boilers—on the upper drum, above the manhole opening.

(*h*) On Scotch marine boilers—on the front head, above the center or right-hand furnace.

(*i*) On Economic boilers—on the rear head, above the central rows of tubes.

(*j*) For other types and new designs—in a location to be approved by the board of boiler inspectors.

5. The standard stamp and the boiler builder's stamps shall not be covered by insulating or other material.

6. All boiler shops in which boilers are constructed for installation in this State shall be open to the members of the state boiler department and inspectors holding certificates of competency as inspectors of steam boilers, at all reasonable hours, for inspection of material, methods of manufacture, workmanship, and testing.

BOILER MANUFACTURING PROCESSES

Shop Equipment. As has been previously stated, the design an engineer may submit for boiler construction is dependent upon the facilities offered by the shop in which the boiler is built.

Boiler shops are equipped with the following tools: plate rolls, plate planers, shears, drill presses, punches, countersinking machines, flanging machines, hydraulic and steam riveters, and a compressed-air system for operating pneumatic machines, such as calkers and chippers. They also have machine shops for doing such machine work as is required for fittings, furnace fronts, etc., and a system of cranes for handling and transporting material. In connection with the above is a storeroom of sufficient size, a forge shop, and an engine and boiler for supplying the shop with the power necessary to operate it.

RIVETED JOINTS

PREPARATION FOR RIVETING

Drilled vs. Punched Rivet Holes. In boiler work the drilling of rivet holes is gradually displacing punching. Punching is cheaper than drilling, but it is more injurious to the plates and not so accurate. It is easy to see that drilling rivet holes, even if twenty are being drilled at once, is done with less strain on the plates than when done by a punch.

Force Required for Punching. The force required to punch a plate gives the best idea of the harm done to the plate. Experiment shows that the resistance of a plate to punching is about the same as its resistance to tensile tearing. Suppose this to be 50,000 pounds per square inch; then the force required to punch the plate is the area cut out times the shearing strength, or $d \times \pi \times t \times 50{,}000$.

$$F = d \times \pi \times t \times 50{,}000$$

in which d is diameter in inches and t is thickness in inches.

For a hole $\frac{3}{4}$ inch in diameter in a $\frac{1}{2}$-inch plate, the force will be

$$\tfrac{3}{4}\times 3.1416\times\tfrac{1}{2}\times 50{,}000=58{,}900 \text{ lb.}$$

A good, ductile plate is but little injured by punching, but if of a hard, steely nature, it is likely to be seriously injured. For this reason wrought-iron plates are usually punched and steel plates are drilled. On the whole, a drilled plate is somewhat stronger than a punched plate for any kind of joint with plates of like thickness.

Reamed Holes. Some boiler makers punch the rivet holes smaller than the desired size and then ream them out. By this process most of the injured metal around the holes is cut away.

Annealing. Another method to overcome the injurious effects of punching is to anneal the plate. The ordinary process of annealing consists of heating the plate to red heat and then allowing it to cool slowly. By this means, hard and brittle iron or steel is made soft and tough. While the metal is hot, the surface becomes oxidized. For most purposes this oxide scale is not harmful, but in some cases it must be removed. As this is expensive, a process of annealing in illuminating gas has been devised. The action of the gas is to reduce the oxide without altering the properties of the piece. The results obtained from annealing depend upon the kind of iron or steel, the temperature to which it is raised, and the rate of cooling. It is a great advantage to all steel of over 64,000 pounds per square inch in tensile strength, but softer steels are little better for the process.

The shops that do the best boiler work proceed in the following manner:

Standard Practice. Holes for rivets in flat plates are drilled while plates are "tacked" together by bolts, the drills being guided by small punched holes in the upper plate only. Plates are taken apart after drilling, scraped free of all burrs and chips, and reassembled for riveting.

Shells are rolled in cylinders and assembled for riveting, and the plates and butt straps are drilled in place $\frac{1}{16}$ inch larger than the rivet.

The foregoing construction insures true holes, and the holes in both plates must match with absolute accuracy, thus avoiding all necessity for the use of a driftpin, which so often produces injurious strains which materialize only after the boiler has been placed in service.

It is important that the burrs be removed from both edges around the rivet holes of every sheet, for if not done, the metal of the burr will form a shallow sharp ring around the rivet when it is driven, or crowd between the plates, thus preventing a tight, flush joint between adjacent sheets.

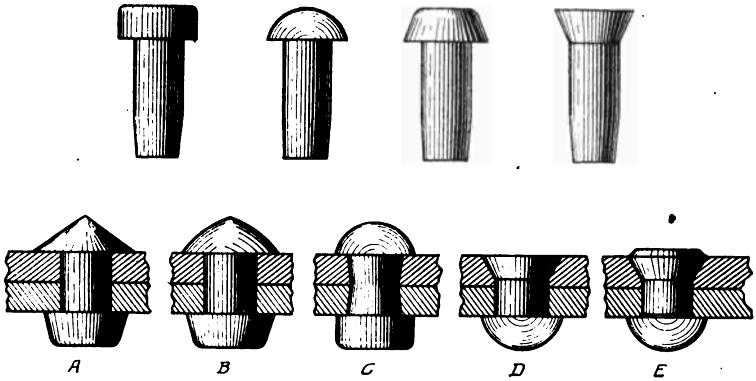


Fig. 7. Types of Rivet Heads Before and After Being Driven

Forms of Rivets. Rivets are forged from round iron or mild steel bars, with a cup- or pan-shaped head. The cylindrical part, called the shank, is a little smaller than the hole in which it enters and has a slight taper. Fig. 7 shows common forms of rivets before and after being driven. As rivets are not as reliable in tension as in shear, they are used mainly at right angles to the pulling force. If the stress is parallel to the axis, bolts may be used, since they are strong in tension. The shearing strength of steel rivets is about 45,000 pounds per square inch, and of iron rivets about 40,000 pounds per square inch. Steel rivets are often used with steel

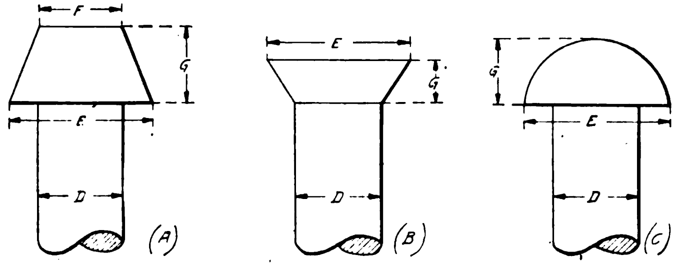


Fig. 8. Diagram of Three Forms of Rivets with Dimensions. Referred to in Table II

TABLE II

Dimensions of Rivets

DIAMETER OF RIVET	CONE HEAD A			COUNTERSUNK B		BUTTON HEAD C	
D	E	F	G	E	G	E	G
$\frac{5}{8}$	$1\frac{1}{16}$	$\frac{19}{32}$	$\frac{9}{16}$	$1\frac{1}{16}$	$\frac{9}{32}$	$1\frac{1}{16}$	$\frac{7}{16}$
$\frac{11}{16}$	$1\frac{1}{8}$	$\frac{21}{32}$	$\frac{39}{64}$	$1\frac{3}{16}$	$\frac{5}{16}$	$1\frac{1}{8}$	$\frac{1}{2}$
$\frac{3}{4}$	$1\frac{1}{4}$	$\frac{23}{32}$	$\frac{21}{32}$	$1\frac{1}{4}$	$\frac{3}{8}$	$1\frac{1}{4}$	$\frac{9}{16}$
$\frac{7}{8}$	$1\frac{7}{16}$	$\frac{13}{16}$	$\frac{3}{4}$	$1\frac{3}{8}$	$\frac{7}{16}$	$1\frac{7}{16}$	$\frac{3}{4}$
1	$1\frac{5}{8}$	$\frac{15}{16}$	$\frac{27}{32}$	$1\frac{5}{8}$	$\frac{1}{2}$	$1\frac{5}{8}$	$\frac{3}{4}$

plates, but many boiler makers prefer to use iron rivets in all cases.

Three types of rivets in use are shown in Fig. 8, Table II, giving the dimensions.

Methods of Driving Rivets. *Hand Method.* Formerly all boiler joints were riveted by hand, but now most riveting is done by machines, except those rivets to which a machine cannot be applied. If done by hand, the red-hot rivet is inserted in the hole, and the second head formed by two riveters working with hammers. This head is either made conical by the hammers alone or finished with a cup-shaped die called a "snap". The latter is the more usual method. The disadvantages of hand riveting are slowness and a tendency to form a shoulder before the rivet fills the hole.

Machine Method. Machine riveting is preferable to hand riveting, as the work is done better, faster, and more accurately; the pressure coming gradually on the entire rivet, compresses it completely into the hole before the head is formed. Before riveting, care should be taken that the plates are close together, so that a shoulder will not be formed between the plates and prevent a good joint. Rivets should always be put in while red-hot, for in this condition they are more easily worked, and when they cool they contract, nipping the plates together in a tight joint.

Hydraulic riveting is more gradual, and is generally preferred to steam riveting. The pressure from the steam riveter often comes as a sudden blow and does not allow time for the rivet to completely fill the hole. In either case the rivet should be held under pressure until black.

Use of Rivets with Countersunk Heads. It is sometimes desirable to rivet with a countersunk head; that is, the rivet does not project above the plate. The countersunk head is formed by hammering down the end of the rivet into the countersink in the plate. This form is shown at *D*, Fig. 7. This joint is often used in shipbuilding and in boiler making when it is necessary to attach mountings. It should always be avoided, if possible, on account of its weakness, and especially when the pulling force acts in the direction of the length of the rivet, as the head has a very insecure hold and is likely to be pulled through the hole.

Temperature of Rivets for Driving. Steel rivets should not be heated to a white heat, as iron rivets are, but to a bright cherry red, for if heated beyond this point they will burn. The fire in which steel rivets are heated should be kept thick, and the draft moderate.

Shaping Butt Straps. Butt straps should be bent into true parts of cylinders of a radius equal to that of the finished boiler drum. Under no circumstances is it considered good practice to bend butt straps by a series of "kinks" to give them an approximate true bend. The edges of plates should be bevel planed to facilitate calking.

Flanging. The construction of practically every design of boiler manufactured from sheets requires the flanging of some of the parts. This is true of water-tube as well as fire-tube boilers. No other part of boiler work, when properly done, requires so much careful design and workmanship as flanging, although in many shops this would not appear to be true. As a first principle, the sheet should not be flanged so that the radius of curvature is small, especially where there is a possibility of "breathing" action being concentrated at the flanged portion. By "breathing" is meant the periodic change of shape between the flat or main portion of the sheet and its flanged edge, due to changes of pressure or to the deformation of other portions of the boiler exerting stresses upon the flanged section.

The next item, and one fully as important, is that the flanged sheet must be uniformly heated to a cherry-red temperature and the work completed before this temperature is lost by radiation. A second heating sets up local stresses which can be only partly removed by annealing. Rather than heat the sheet more than once, some other form of design must be selected if necessary.

If it is impracticable to heat an entire metal piece for a small flange, as, for instance, at the end of an internal furnace of a Scotch boiler, the heat is applied locally, but the whole must be carefully annealed after the flanging is done.

Some boiler shops perform all simple flange work without heating the sheets. It may be stated that this practice should always be discouraged when intended for use in constructing high-pressure boilers. Another practice which is in disfavor is hammering by hand; in fact flanging by any other process than by the use of suitable machinery should be avoided in building high-pressure boilers.

TYPES OF RIVETED JOINTS

Efficiency of a Joint. It is obvious that a plate is weakened by removing the metal of rivet holes. It is customary to speak of the strength of a riveted joint in terms of the percentage of the strength preserved of the original plate; the ratio of the joint strength to that of the original sheet, expressed in decimals, is called the *efficiency* of the joint. Riveted joints may fail in several ways: (1) By shearing the rivets. (2) By tearing the plate at the reduced section between the rivets. (3) By crushing the plate or rivets where they are in contact. (4) By cracking the plate between the rivet hole and the edge of the plate. As in practice the lap can always be made sufficiently wide, a joint need never fail in the last-named way.

Classification. The names given to the several kinds of joints are descriptive, as, for instance, the term "lap joint" is applied to a joint in which the edges of the sheet to be joined overlap. A "butt joint" is the name given to a joint in which the edges of the joined sheet do not overlap but meet each other edge on, while the fastening is accomplished by the use of straps which overlap the edges to be united.

The number of rows of rivets parallel to the length of the joint are expressed in the terms "single", "double", "treble", etc. In butt-joint seams the word designating the number of rows of rivets refers to the number of rows on one side of the joint only; thus a treble-riveted butt joint has actually six longitudinally rows of rivets, three on each side of the meeting line of the joined sheets.

Lap Joints. Circumferential or girth seams are usually lap joints since the tendency to rupture at these seams is only one-half as great as at the longitudinal seams.

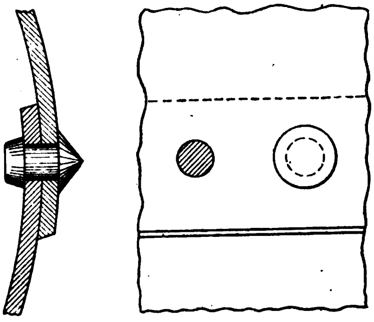


Fig. 9. Single-Riveted Lap Joint

Longitudinal lap seams are usually double riveted, and for higher pressures, treble riveted. Fig. 9 shows the most simple form of this joint and is called a single-riveted lap joint. Double-riveted lap joints may have the rivets arranged as shown in Figs. 10 and 11. The former joint is called a double-riveted lap joint with chain riveting, and the latter a double-riveted lap joint with staggered riveting. The staggered riveting is a little weaker than the chain, but the joint is usually tighter and less lap is required.

Efficiency. The efficiency of lap joints depends upon the pitch and diameter of the rivets, the thickness of the plates, and the number of rows. The efficiency is also somewhat altered if the plates are drilled instead of punched. As there are so many conditions we can give only rough average efficiencies.

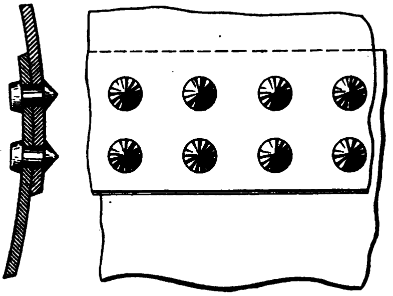


Fig. 10. Double-Riveted Lap Joint, Chain Riveting

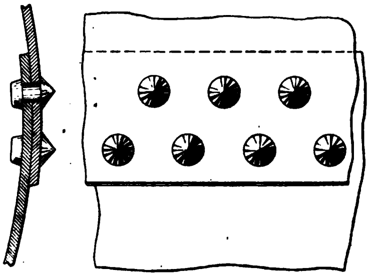


Fig. 11. Double-Riveted Lap Joint, Staggered Riveting

Lap joint, single riveted, efficiency about 56%
Lap joint, double riveted, efficiency about 70%
Lap joint, treble riveted, efficiency about 72%

It is well to remember that the efficiency figures are calculated without reference to the creation of an eccentric load on the sheets and the rivets. The true efficiency figures are appreciably less than

TABLE III

Proportions of Riveted Lap Joints

Thickness of Plate (In.)	Diameter of Rivet (In.)	Diameter of Hole (In.)	Pitch, Inches		Efficiency	
			Single Riveted	Double Riveted	Single Riveted	Double Riveted
$\frac{1}{4}$	$\frac{5}{8}$	$\frac{11}{16}$	2	3	.66	.77
$\frac{5}{16}$	$\frac{11}{16}$	$\frac{3}{4}$	$2\frac{1}{16}$	$3\frac{1}{8}$	.64	.76
$\frac{3}{8}$	$\frac{3}{4}$	$\frac{13}{16}$	$2\frac{1}{8}$	$3\frac{1}{4}$	.62	.75
$\frac{7}{16}$	$\frac{13}{16}$	$\frac{7}{8}$	$2\frac{3}{16}$	$3\frac{3}{8}$	.60	.74
$\frac{1}{2}$	$\frac{7}{8}$	$\frac{15}{16}$	$2\frac{1}{4}$	$3\frac{1}{2}$	.58	.73

those calculated, for it is impossible when using lap joints to avoid the tendency of the sheet to pull into a curved line of a radius equal to that of the cylinder of which it forms a part.

Table III gives the proportions of riveted lap joints for average practice in boilers of up to about 150 pounds pressure.

The probable efficiency of joints may be calculated by mathematics, but the actual efficiency can be obtained only by means of the testing machine. In testing, a piece of uncut plate, the size of which depends upon the capacity of the machine, is first tested. Then a portion of the joint of approximately the same size is tested. The ratio of the breaking strength of the joint to that of the uncut plate is its efficiency.

Butt Joints. Longitudinal seams, except for small diameters, are almost always made with butt joints. These joints are seldom single riveted because as such they are not much stronger than a double-riveted lap joint and are more expensive. If, however, they are made with double butt straps and double or treble riveted, the joint shows a high efficiency. The two butt straps may be of the same width or the inner may be wider than the outer. Fig. 12 shows a double-riveted butt joint with two butt straps. A treble-riveted butt joint is shown in Fig. 13.

Efficiency. The following are approximate efficiencies:

Butt joints, single riveted, efficiency about 65%
Butt joints, double riveted, efficiency about 75%
Butt joints, treble riveted, efficiency about 85%

Butt straps should be at least five-eighths the thickness of the shell plates. In all of the butt joints illustrated the outer strap is made narrower than the inside strap, in order to provide a calking edge on the outside with as little *pitch* or distance between the rivets

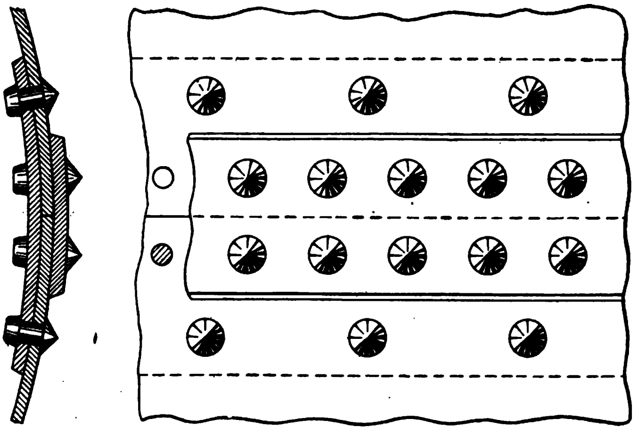


Fig. 12. Double-Riveted Butt Joint

as possible; the effectiveness of calking is dependent upon the ability of the rivets to hold the sheets in close contact. Obviously, the

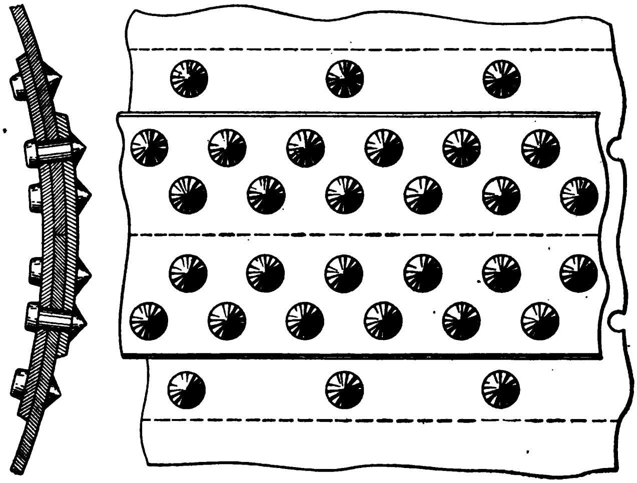


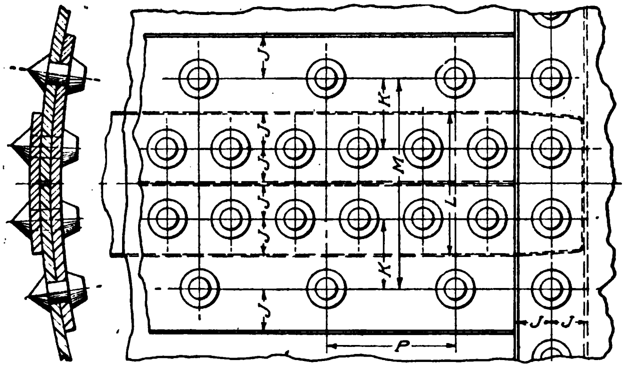
Fig. 13. Treble-Riveted Butt Joint

farther apart the rivets are along the calking edge, the easier it is for the sheet edge to spring away from its companion sheet.

TABLE IV

Efficiencies of Double-Butt-Strap, Double-Riveted Joints

Butt and Double-Strap Joints, Double Riveted, in Which the Pitch of Rivets in Outer Row Is Twice the Pitch of Rivets in the Second Row.



7/16" Plate
3/8" Butt Straps (or thicker)
7/8" Rivet (before driving)

Diameter of Rivet Hole	DIMENSIONS				LENGTH OF RIVETS BEFORE DRIVING	
	J	K	L	M	Outer Row	Second Row
29/32"	1 3/8"	2 15/16"	5 1/2"	11 3/8"	2 3/8"	2 3/4"
15/16"	1 7/16"	3"	5 3/4"	11 3/4"	2 3/8"	2 7/8"

P Pitch of Rivets in Outer Row	TENSILE STRENGTH OF PLATE (POUNDS)							
	55000		56000		57000		58000	
	DIAMETER OF RIVET HOLE							
	29/32"	15/16"	29/32"	15/16"	29/32"	15/16"	29/32"	15/16"
4 1/2"	B 79.8	B 79.1	B 79.8	B 79.1	B 79.8	B 79.1	B 79.8	B 79.1
4 9/16"	B 80.1	B 79.4	B 80.1	B 79.4	B 80.1	B 79.4	B 80.1	B 79.4
4 5/8"	B 80.4	B 79.7	B 80.4	B 79.7	B 80.4	B 79.7	B 80.4	B 79.7
4 11/16"	B 80.6	B 80.0	B 80.6	B 80.0	B 80.6	B 80.0	B 80.6	B 80.0
4 3/4"	B 80.9	B 80.2	B 80.9	B 80.2	B 80.9	B 80.2	B 80.9	B 80.2
4 13/16"	B 81.1	B 80.5	B 81.1	B 80.5	B 81.1	B 80.5	B 81.1	B 80.5
4 7/8"	B 81.4	B 80.7	B 81.4	B 80.7	B 81.4	B 80.7	B 81.4	B 80.7
4 15/16"	B 81.6	B 81.0	B 81.6	B 81.0	B 81.6	B 81.0	B **81.6**	B 81.0
5—"	B 81.8	B 81.2	B 81.8	B 81.2	B **81.8**	B 81.2	G 80.7	B 81.2
5 1/16"	B 82.1	B 81.4	B **82.1**	B 81.4	G 81.1	B 81.4	G 79.7	B 81.4
5 1/8"	B **82.3**	B 81.7	G 81.5	B 81.7	G 80.1	B 81.7	G 78.7	B **81.7**
5 3/16"	G 82.0	B 81.9	G 80.5	B 81.9	G 79.1	B **81.9**	G 77.8	G 81.2
5 1/4"	G 81.0	B 82.1	G 79.6	B **82.1**	G 78.2	G 81.6	G 76.+	G 80.2
5 5/16"	G 80.1	B 82.3	G 78.6	G **82.1**	G 77.3	G 80.7	G 75.+	G 79.3
5 3/8"	G 79.1	B **82.5**	G 77.7	G 81.1	G 76.4	G 79.7	G 75.+	G 78.3
5 7/16"	G 78.2	G 81.7	G 76.8	G 80.2	G 75.+	G 78.8	G 74.+	G 77.+
5 1/2"	G 77.3	G 80.7	G 76.+	G 79.3	G 74.+	G 77.+	G 73.+	G 76.+
5 9/16"	G 76.5	G 79.8	G 75.+	G 78.4	G 73.+	G 77.+	G 72.+	G 75.+
5 5/8"	G 75.6	G 78.9	G 74.+	G 77.+	G 73.+	G 76.+	G 71.+	G 74.+
5 11/16"	G 74.+	G 78.+	G 73.+	G 76.+	G 72.+	G 75.+	G 70.+	G 74.
5 3/4"	G 73.+	G 77.+	G 72.+	G 75.+	G 71.+	G 74.+	G 70.+	G 73.+

The letters B or G show the manner in which the joint will fail.

B = Strength of plate between rivet holes in outer row.

G = Crushing strength of plate in front of two (2) rivets, plus the shearing strength of one (1) rivet in single shear.

NOTE.—The highest efficiency in each column is shown in heavy figures.

The criticism raised against lap joints as offering eccentric loads does not hold with double-butt-strap construction.

Tables have been prepared for all types of riveted joints likely to be used, giving the efficiencies obtained by the use of different sheet thicknesses, different rivet sizes, and different rivet spacings. These include lap joints and butt joints; in the latter case, as complicated as quintuple riveting. In Table IV is given a sample data sheet of a double-butt-strapped, double-riveted seam for a $\frac{7}{16}$-inch plate. Note that several kinds of joint failures are worked out.

CALKING

In order that riveted joints of boilers may be steam and water tight, they require calking. This process upsets the metal of the overlapping plate, forcing it into close contact with the lower plate, and rendering the joint steam tight.

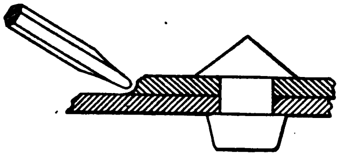


Fig. 14. Correct Method of Calking

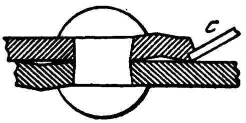


Fig. 15. Incorrect Method of Calking

Calking Tools. *Hand Tools.* The calking tool is similar to a chisel, the end having a variety of shapes. Fig. 14 shows a round-nosed tool which fullers the upper plate down without cutting the lower plate; but it is hard to start, and in calking with such a tool the edge is first started with a sharper round-nosed tool, and then finished with one as indicated in the figure. If a square-end tool is used, as shown in Fig. 15, the under plate is likely to be cut, and the plates between the edge and the rivet be separated. The most common form of calking tool is similar to the one shown in Fig. 14. Sometimes the end is flat, with a slight bevel, and not round.

Pneumatic Calking Machine. A pneumatic calking machine is often used in boiler shops, as it does this work about four times as rapidly as it can be done by hand. The tool resembles a pneumatic hammer in appearance. Air is supplied through a flexible tube, at a pressure of about 70 pounds per square inch.

Proper Method. A slight bevel given the plates makes calking more easily and securely done. When the calking tool is thin it is sometimes driven by careless workmen into the joint, wedging the plates open as shown in Fig. 15. Severe and careless calking is very injurious to boilers. On the inside it often causes grooving and fracture, and the fracture of plates then follows the line of calking rather than the line of rivet holes.

WELDED JOINTS

Advantages and Disadvantages. Welded joints for boiler work would be desirable if there were greater certainty in the results. By their use deposits which accumulate on and around rivet heads and joints, corrosion caused by leakage, and loose rivets and calking would be done away with. Moreover, a perfectly welded joint is stronger than the best riveted joint, and approximates nearly to the original strength of the plate. Welded steam drums are used for water-tube boilers of the marine type and in the construction of cross pipes, mud drums, etc. Unfortunately it is impossible, from external appearances, to judge the soundness of a welded joint. The lack of tests on such joints and the small amount of information on the subject render the results of experiments of little value. The weld is best made when the edges of the plates are upset, at red heat, to nearly double the plate thickness, and beveled to an angle of about 45 degrees. The edges are then heated together, and the weld made by hammering the joint down to the original thickness of the plate.

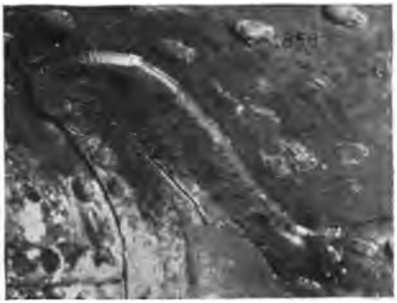


Fig. 16. Weld in Locomotive Fire Box
Courtesy of C & C Electric and Manufacturing Company

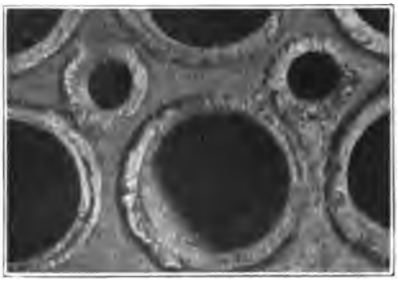


Fig. 17. Electrically Welded Boiler Flues
Courtesy of Railway Master Mechanic

Welding in boiler work finds its greatest usefulness in repair work, especially in such cases where any other method of repair would necessitate the removal of boiler sheets, or in places where any other work is difficult owing to lack of room. Boiler tubes are sometimes welded to the tube sheets after the usual expanding is done. Figs. 16 and 17 are illustrations of cases in point.

It is to be said in connection with welding of cracked boiler sheets, that there is danger that the sheet metal may have crystallized so much as to be unsuitable for good welding work. Many repair jobs are failures from this cause, which makes welding in boiler work less attractive than it otherwise would be. The welding of tubes into tube sheets of boilers makes it difficult to replace the tubes when they fail at a different place than the weld; it has been for this reason that welding for this purpose has made very little progress except in very special boiler designs. On the other hand, the welding of short pieces to the ends of tubes, after the ends have been cut off for removal from boilers, has long been successfully practiced.

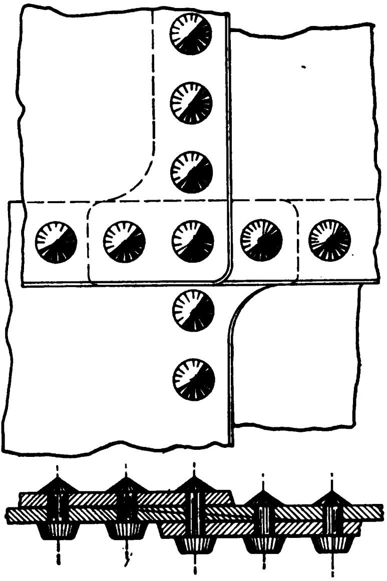


Fig. 18. Method of Handling Joint when Three or More Plates Meet

ARRANGEMENTS OF PLATES AND JOINTS

Transverse and Longitudinal Seams. The tendency of a cylindrical shell carrying internal pressure to fail longitudinally is twice that circumferentially. Since this is the case, lap joints are used for transverse or girth seams, and stronger forms (butt joints) are used for the longitudinal seams.

Complicated Joints. At the junction of three or more plates, where the circumferential and longitudinal joints meet, ordinary riveted joints would be too thick. To overcome this difficulty, two or more plates are forged thin at the joint, as shown in Fig. 18. The illustration shows a needless complication of joints at one place, but is given to emphasize scarfing as a means of obtaining strength.

Whenever longitudinal and girth seams meet, the plates should be arranged to "break joints"; that is, one longitudinal seam should not be a continuation of another. The proper arrangement is shown in Fig. 19.

In both vertical and horizontal boilers the inside lap is made to face downward, so that it will not form a ledge for the collection of sediment.

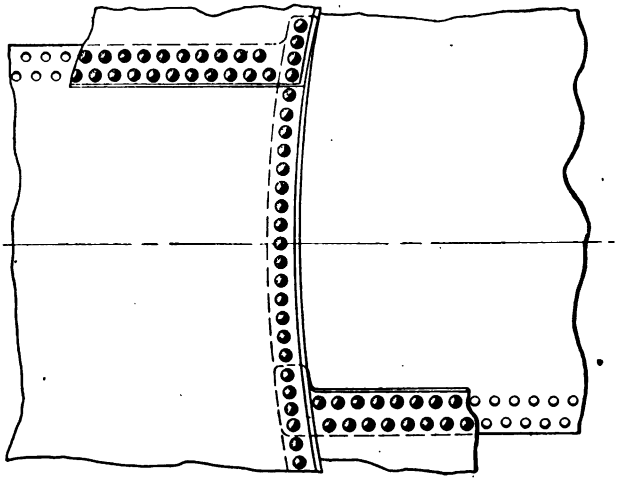


Fig. 19. Part of Boiler Shell Showing Method of Breaking Joints

Joints in Internally-Fired Boilers. The belts of plates which make up the length of the drums are sometimes arranged conically, with the outer sheet placed toward the direction of natural drainage. When the boiler is slightly inclined toward the front end, this conical arrangement facilitates draining and cleaning, as the dirt is removed at the front end. This is a great advantage in internally-fired boilers, as they are difficult to clean in any event.

Joints in Vertical Boilers. In long vertical boilers the ring seams are arranged with the inside lap facing downward, so as not to have a ledge for sediment. Sometimes the belts of locomotive boilers are arranged telescopically, with the largest diameter at the fire-box end. Of late years the best makers use larger plates than formerly. This is advantageous, especially in externally-fired, multitubular boilers, as the single seam is placed above the water level, and therefore is away from the fire.

Water-Leg Construction. The portion of internally-fired boilers between the shell and the furnace is called the water leg. Figs. 20 to 26, inclusive, illustrate the method of constructing the water leg and the joints around the furnace doors. Figs. 20, 21, and 22 show three methods of constructing the water leg. In Fig. 20 the exterior plate and the furnace plate are riveted to the ring *D* by means of long rivets. This ring is usually made of wrought iron, but in many cheap boilers it is of cast iron. In Fig. 21 the two plates are riveted to the flanged ring *D*. This construction is better than the solid cast-iron ring, on account of flexibility, but the junction of the plates *D* and *C* forms a corner in which sediment is deposited. In Fig. 22 the plate *B* is flanged and riveted to *C*. This arrangement requires less riveting than the one shown in Fig. 21. Figs. 20, 21, and 22 also show three forms of construction of the joints

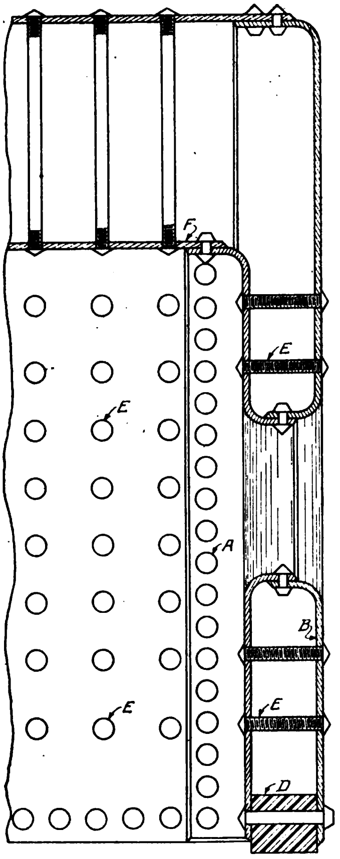


Fig. 20. Form of Water-Leg Construction

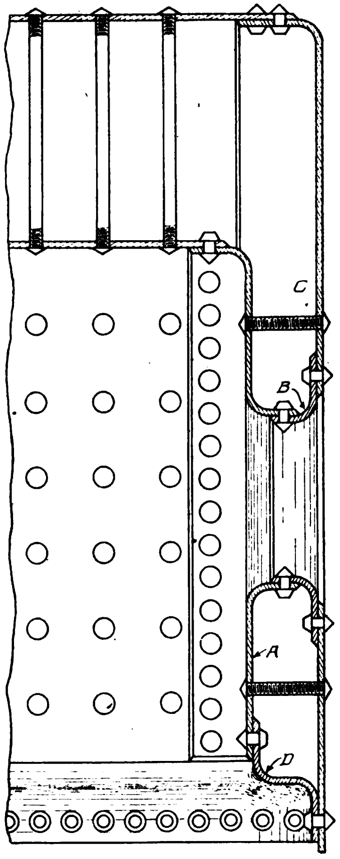


Fig. 21. Form of Water-Leg Construction

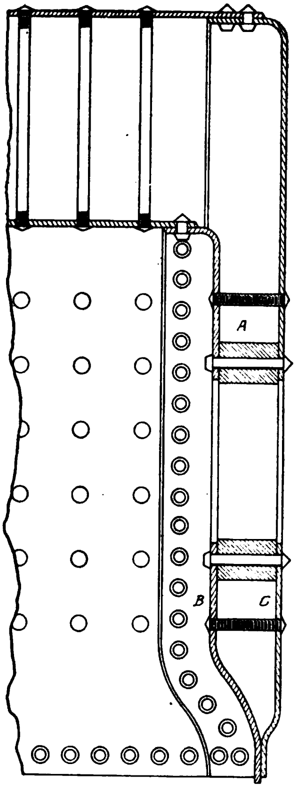


Fig. 22. Form of Water-Leg Construction

around the furnace door. In Fig. 20 both the exterior plate and the furnace sheet are flanged and riveted together. This is shown in an enlarged view in Fig. 23. The construction shown in Figs. 21, 24, and 25 is not as good as that in Figs. 20 and 23, because of the extra riveting; also, it has two corners, *B* and *C*, for the deposit of sediment. Fig. 22 shows a somewhat different form of furnace-door construction, the two plates being riveted to a cast-iron ring. This form is better shown in Fig. 26. It makes this part of the boiler too rigid, but it has the advantage of not having rivet heads in the door opening to wear off. In general, the flanged-ring method is preferable to the cast-iron ring, because of greater freedom for expansion, but the flanged ring forms undesirable corners for sediment accumulation.

Corner Joint Construction. In almost every boiler, plates must be connected at right angles. An example of this is seen where the end plates are jointed to the shell plates of cylindrical boilers. There are three principal methods: riveting both plates to an angle iron, riveting both to a flanged ring, and flanging the end plate. In Fig. 27 the two plates are riveted to an angle iron, which is made of wrought or cast iron. This construction is too rigid; the constant variations of temperature cause repeated changes of form, which tend to crack the angle iron on the inside of the plate at the joint. Corrosion increases the evil, as it rapidly attacks iron which has once been cracked or broken. There is no

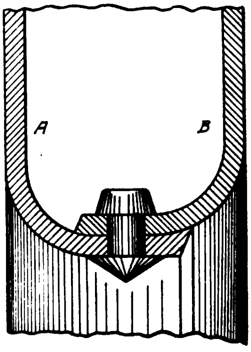


Fig. 23. Enlarged Section of Door Joint, Fig. 20

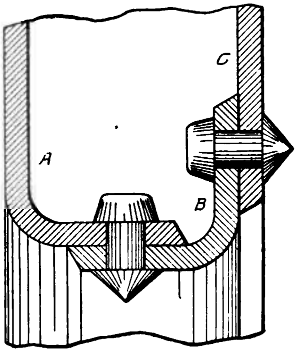


Fig. 24. Enlarged Section of Joint Construction in Fig. 21

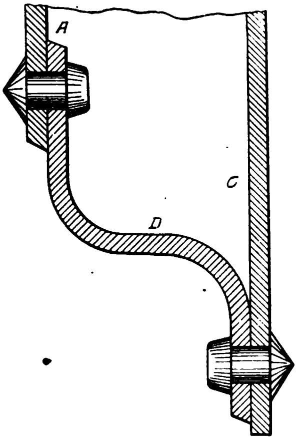


Fig. 25. Enlarged Section of Joint Construction in Fig. 21

definite rule for the dimensions of these angle irons, but it is safe to make the mean thickness a little greater than that of the plates.

The forms shown in Figs. 28 and 29 are better. The head is flanged and riveted to the shell plates. The flanging makes a more flexible joint. The radius of the curve of the flange should be at least four times the thickness of the plate. The head and shell are sometimes connected to a flanged ring, as shown in Fig. 30; the extra row of rivets makes a more complex joint, and the construction, since it need not be used, should be avoided.

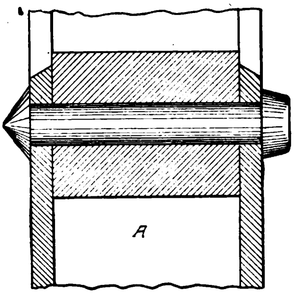


Fig. 26. Enlarged Section of Joint Construction in Fig. 22

In vertical boilers the external fire box is joined to the cylindrical shell by riveted joints. Figs. 31 and 32 show two forms, that in Fig. 31 being the better on account of the flanged ring, which allows expansion and contraction of the shell and furnace plates.

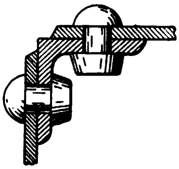


Fig 27. Corner Joint with Angle Plate

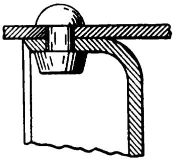


Fig. 28. Corner Joint with Flanged Head

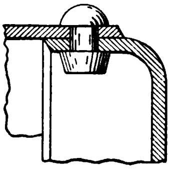


Fig. 29. Corner Joint with Flanged Head

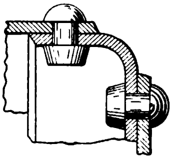


Fig. 30. Corner Joint with Flange Ring

Sometimes the case occurs of connecting two plates which are parallel and near together. At the bottom of the locomotive fire box a connection must be made between the inner and outer shells of the fire box. Several methods for this construction are shown in Fig. 33. Fig. 33*A* is too complicated and is undesirable, both on account of the numerous rivets and angle irons, and on account of the inside joints, which cannot be calked. Fig. 33*B* is better, since it has but one angle iron; it has, however, the undesirable inside joint.

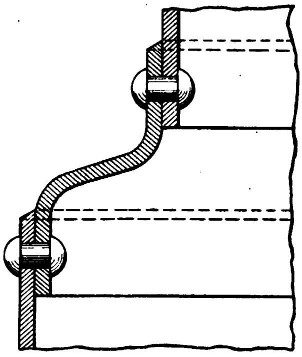


Fig. 31. External Fire-Box Connection with Flanged Ring

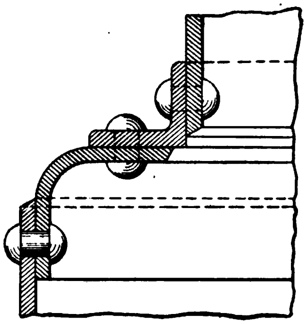


Fig. 32 External Fire-Box Connection with Angle Plate

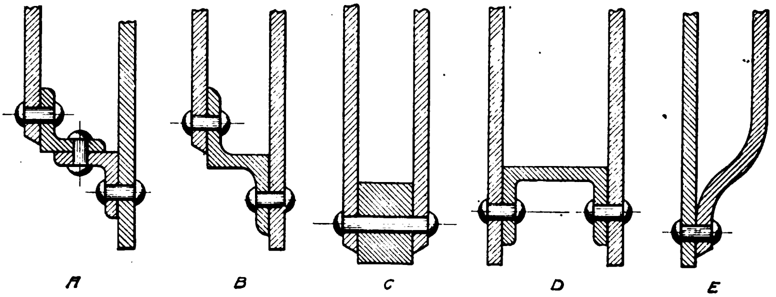


Fig. 33. Different Forms of Locomotive Fire-Box Connections

Fig. 33*D* is a good joint, the form of connecting ring being channel iron. Fig. 33*E*, as we have seen, is a good flexible joint, but it has the undesirable corner where sediment lodges.

It is to be remembered that the use of structural steel in the construction of high-pressure boilers should be avoided, and to this extent the forms of water-leg construction illustrated cannot be universally used.

MANHOLES

Location. In order to provide access to the inside of boilers, manholes are constructed either in the flat end sheets of the shells or through the curved cylindrical sheet. These openings are, of course, located so that highly heated gases will not strike them, and they are made elliptical in shape, as this form offers the greatest opening for a given amount of material removed; it also lends itself best to the conservation of the strength of the removed boiler section, and, having one dimension greater than the other, permits the insertion of a cover plate for the opening which will carry the internal pressure by being forced upon its seat. When located in the cylindrical surface, the longer dimension is in the direction of the girth seam, as the tendency to rupture in that direction is only half that of the longitudinal dimension of the shell.

Size of Opening. Manhole openings should not be less than 11 by 15 inches in size in the clear opening and, if strength permits, it is well to make them larger in both dimensions. In order to strengthen the opening, a manhole frame or reinforcing ring is riveted around the openings, as shown in Fig. 34.

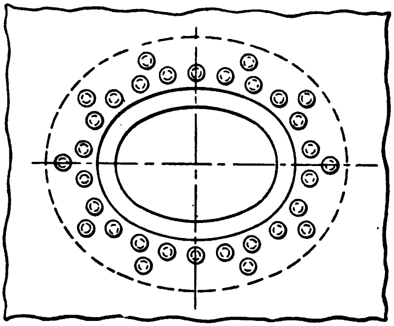


Fig. 34. Method of Riveting Manhole Frames to Shells or Drums with Two Rows of Rivets

Frame Construction. This frame or other reinforcing ring is made of wrought or cast steel having a net cross-sectional area, on a line parallel to the axis of the shell, not less than the cross-sectional area of shell plate removed on the same line, and of no less thickness than the shell plate.

Manhole frames on shells or drums must have proper curvature, and on boilers over 48 inches in diameter should be riveted to the shell or drum with two rows of rivets, which may be pitched as shown in Fig. 34. The strength of the rivets in shear on all manhole frames and reinforcing rings should not be less than the tensile strength of the shell plate removed, on a line parallel to the axis of the shell, through the center of the manhole.

Manhole plates should be made of wrought or cast steel.

Construction with Flanged Edges. Manholes are sometimes made by flanging the edge of the hole inwardly, thus forming out of the sheet itself a reinforcing ring of great rigidity. The flanged edge is faced off to offer a suitable seat for the manhole plate. When this form of construction is used, especially in high-pressure boiler construction, a reinforcing ring is sometimes shrunk around the flanged edge, and both are then faced off. This construction, when properly done, is probably the best possible form to build.

Handholes. Handholes are needed to give access to the inside of boilers for the removal of sediment, for washing, and, in the case of water-tube boilers, for the cleaning and replacing of tubes. The principles of construction are the same for handholes as for manholes, though the use of reinforcing rings is not resorted to because, being smaller, the strength of the sheet is not so seriously impaired as with manholes. They are always made elliptical in shape except in water-tube boilers, in which case they may be of round or of irregular shape. The elliptical shape has the advantage of permitting the plate to be independently removable, at the same time carrying the pressure by forcing the handhole plate upon its seat. The flanging of the handhole openings in water-tube boilers is rapidly finding greater use on account of the greater stiffness of the plate around the hole and for the other advantages just mentioned.

STAYS

Necessity of Staying Flat Surfaces. When under steam, a cylindrical shell is under stress due to internal pressure in two directions, namely, transversely, by a circumferential stress due to the pressure tending to burst the shell by enlarging its circumference, and, longitudinally, by the pressure on the ends. A spherical boiler would require no stays, because a sphere subjected to internal pressure tends to enlarge but not to change its shape. All flat surfaces in boilers must be stayed, otherwise the internal pressure would bulge them out and tend to make them spherical in shape. To avoid stays the ends of steam drums on high-pressure water-tube boilers are made hemispherical, or nearly so.

The first and most important requirement in staying is to have a sufficient number of stays, so they will entirely support the plate without regard to its own stiffness. The second is to have them so placed as to present the least obstruction to free inspection, and, third, to have them so arranged as to allow free circulation of water. Too much care cannot be taken in fitting stays and braces, as they are out of sight for long periods, and a knowledge of their exact condition is not always easy to be obtained. In fire-tube boilers the principal surfaces stayed are: the flat ends, crown sheets, water legs of locomotive boilers, and combustion chambers of cylindrical marine boilers. In the case of most Scotch marine boilers, the diameter is large compared to the length; hence there is considerable flat surface. All the plates that are not cylindrical or hemispherical must be stayed. The details should be arranged for each boiler; a few general methods and cautions may, however, be given.

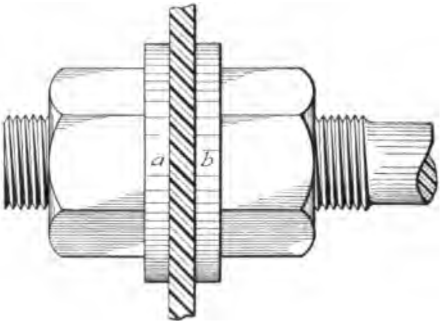


Fig. 35. Method of Fastening Stay Rods

Simple Stay Rod. The most common and simple form of stay is a plain rod. It is used to stay the flat ends of short boilers. This stay is a plain rod passing through the steam space and having the ends fastened to the heads. The ends are fastened and the length adjusted by a variety of methods, the simplest being nuts on both sides of the plate, as shown in Fig. 35. The copper washers *a* and *b* strengthen the plate and prevent abrasion by the nuts. In place of the nuts the rod is often bolted to angle irons, which are riveted to the plates. In this case, turnbuckles similar to the one shown in Fig. 36 are used for adjusting the length.

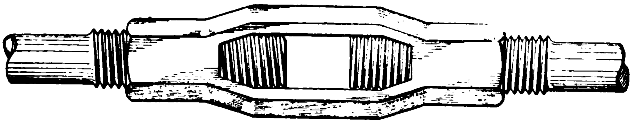


Fig. 36. Turnbuckle Used to Tighten Stay Rods

The stays are made of wrought iron or steel, with an allowable stress of 5000 to 7000 pounds per square inch. If the ends are fastened to riveted angle irons, the combined area of the rivets is made a little greater than that of the rod.

Gusset Stay. If a boiler is long, say, more than 20 feet, through stays would sag in the middle and not take up the full stress on the end plates. For long boilers, gusset and diagonal stays are used. The form of boiler stay shown in Fig. 37 is made of wrought-iron plate riveted to angle irons, the angle irons being riveted to the end and shell. Boilers of the Cornish, Lancashire, and Galloway types often have this kind of stay. These boilers are internally fired and, as the variation of temperature causes expansion and contraction, great care should be used in placing the gusset stay. If the stay is too near the flange or if too many stays are used, the head will be too rigid and have a tendency to crack.

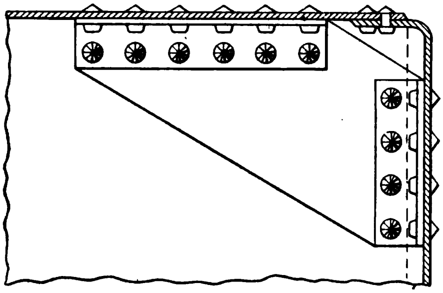


Fig. 37. Corner of Boiler with Gusset Stay

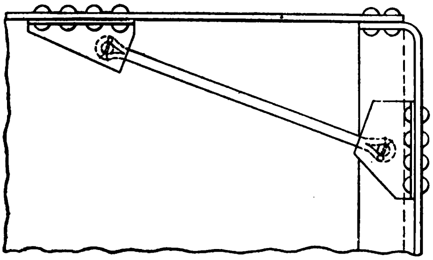


Fig. 38. Diagonal Stay Using Angle Irons and Pins

Diagonal Stays. A form of diagonal stay is shown in Fig. 38. The plain rod is connected to angle irons by means of pins. The angle irons are fastened to the shell and end by rivets or bolts. Another form of diagonal stay, called the crowfoot, is shown in Fig. 39. The two ends are bolted or riveted to the end and shell.

The angle between the shell plate and stay rod should be small—not more than 30 degrees. The rod itself is designed for tensile strength, since the diagonal pull may be easily reduced to an equivalent direct pull. A large factor of safety is used to provide for future corrosion.

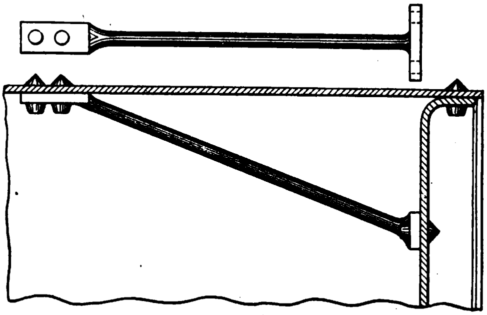


Fig. 39. Form of Crowfoot Stay

For marine boilers, a modified crowfoot stay, Fig. 40, is often used. The end passing through the head is supplied with nuts and taper washers, the washers having the proper taper to allow the nuts to be set up tightly against them.

It should be added that boiler heads are further stiffened by channel bars or angles placed along the line of holes for the through stay rods.

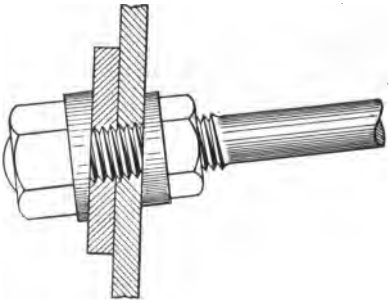


Fig. 40. Form of Fastener for Marine Type of Crowfoot Stay

Riveted Stay Bolts. In locomotive fire boxes and in the combustion chambers of marine boilers, there are two flat or slightly curved surfaces which must be stayed together. These are riveted by short screw stay bolts. The bolts shown in Figs. 41 and 42 are screwed in place, and the ends riveted over. In marine boilers these stays are fastened with nuts, as shown in Fig. 43, instead of being riveted. Sometimes the bolt is threaded the entire length, as in Fig. 41, or is turned off smooth in the center, as in Fig. 42. The smooth surface resists corrosion, and is less likely to fracture than the threaded bolt. Sometimes a small hole is drilled in the end, so that if the bolt breaks, the escaping steam will give warning. This is shown at *a* Fig. 42. These bolts are $\frac{7}{8}$ inch or 1 inch in diameter.

The stresses which come on a stay bolt are not the same as the stresses on rivets or on ordinary stay rods; as a matter of fact, stay bolts fail by a bending stress, and generally fracture just inside the outside sheet, due to the unequal expansion between combustion chamber, or furnace, and the outside boiler shell. Owing to this difference of expansion, flexible stay bolts have been designed, but have not come into general use; nor are they likely to, as they occupy considerable space and are much more complicated than the simple stay bolt. Stay bolts are made from the best quality of refined iron, which has been found to stand the stresses of alternate heating and cooling better than mild steel. Iron stay bolts are more durable, because of the fibrous nature of the iron.

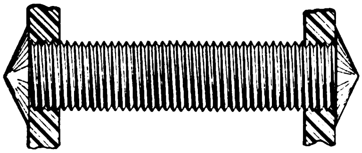


Fig. 41. Riveted Locomotive Stay

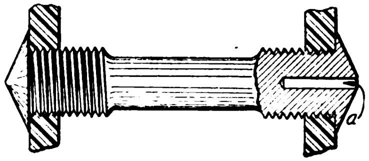


Fig. 42. Drilled Form of Riveted Locomotive Stay

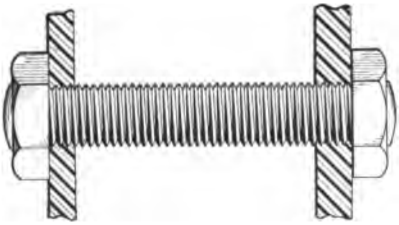


Fig. 43. Marine Stay Held with Nuts

Stiffening Angles. Where the size of the boiler shell is not large and the pressure is not especially high, it is permissible to use stiffening angles in lieu of stays to prevent the end sheets of cylindrical shells from bulging. The accompanying illustration, Fig. 44, shows the details of such a construction and needs no further explanation. The illustration can be studied to advantage in other particulars as it gives the tube spacing, the size and location of a handhole, the proper levels of the gage cocks and the water, and the location of a fusible plug in the case of a 36-inch horizontal tubular boiler.

Crown Sheet Supports. The crown sheets of fire boxes and tops of combustion chambers are usually stayed by crown bars, which extend across the flat surfaces, Fig. 45, the ends resting on the

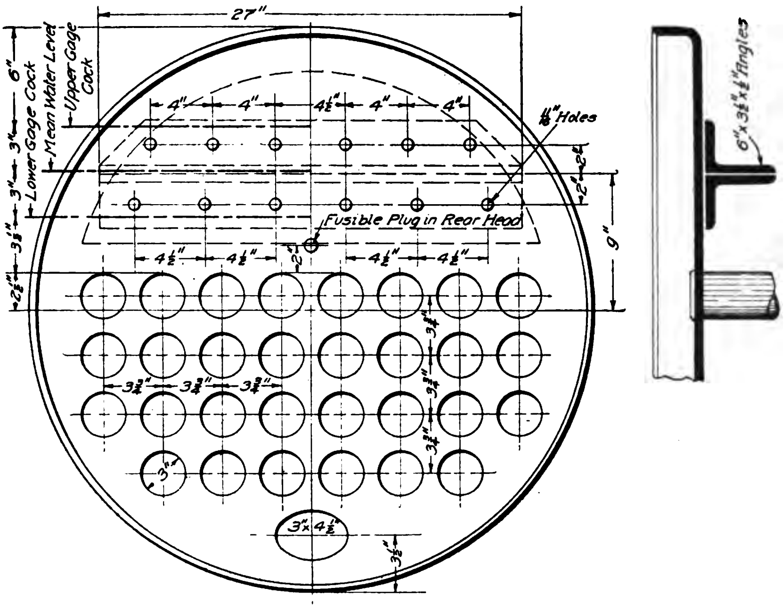


Fig. 44. Method of Staying Boiler Heads with Steel Angles

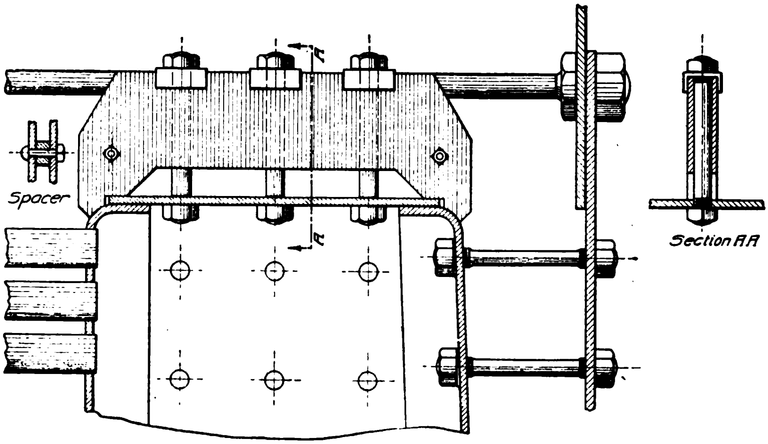
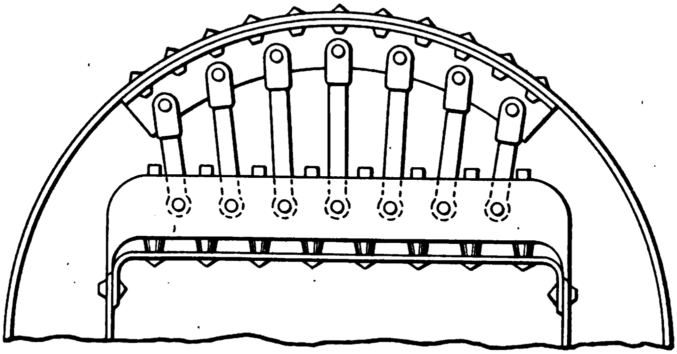


Fig. 45. Crown Sheet Support for Combustion Chamber in Scotch Marine Boiler

side plates. Bolts about 4 inches apart connect the crown sheet to this girder. The girder may be a solid bar, or it may be made up of two flat plates bolted or riveted together, as shown in the figure, the stay bolts being placed between the plates at intervals of about 4 inches. Either bolts or rivets may be used to keep the plates which form the girder from spreading. Projections are sometimes forged on the bottom of the girder, so that the stay bolts may be screwed up tightly without bending the plate.

The depth of the plates which make up the girder varies from 4 to 6 inches. They are from $\frac{5}{8}$ to $\frac{3}{4}$ inch in thickness. If bolts $\frac{7}{8}$ inch in diameter are used, the distance between the plates is usually 1 inch, but if bolts 1 inch in diameter are used, the distance should be $1\frac{1}{8}$ inches. The ends of the bars which rest upon the side plates should be carefully fitted to make a good bearing, and the area should be sufficient to prevent crushing of the end plates. The distance between the crown sheet and the girder should be at least $1\frac{1}{2}$ inches, so there will be good circulation and the plates may be readily cleaned.



Fig, 46. Crown Sheet Support by Use of Sling Stays

In some cases the girder is supported from the shell by sling stays, as shown in Fig. 46. The sling stays are connected to the girder and to an angle iron, or T-iron, which is riveted to the shell. The angle iron stiffens the shell. In designing this form of stay it is usual to make the girder strong enough to support the crown sheet without any sling stays, and these stays are used for additional support.

TABLE V

Maximum Allowable Stress for Stays and Stay Bolts

Material and Type	Size up to and Including 1¼ In. Diameter or Equivalent Area, Lb.	Size Over 1¼ In. Diameter or Equivalent Area, Lb.
Weldless mild steel head to head or through stays	8000	9000
Weldless mild steel diagonal or crowfoot stays	7500	8000
Weldless wrought-iron head to head or through stays	7000	7500
Weldless wrought-iron diagonal or crowfoot stays	6500	7000
Welded mild steel or wrought-iron stays	6000	6000
Mild steel or wrought-iron stay bolts	6500	7000

A horizontal tubular boiler, having a manhole below the tubes, should have one or more stays on each side of the manhole, the rear ends of which should be attached to the rear head of the boiler and the front ends allowed to pass through the front head secured with nuts, inside and out. The center line of such stays at the front head should not be below the center line of the manhole.

Stay rods ought not to exceed 3 feet in length when screwed through the sheets and riveted over.

TABLE VI

Allowable Loads on Stay Bolts with V-Threads, 12 Threads per Inch

Outside Diameter of Stay Bolts (In.)		Diameter at Bottom of Thread (In.)	Net Cross-Sectional Area (at Bottom of Thread) (Sq. In.)	Allowable Load at 6500 Lb. Stress, per Sq. In.	Allowable Load at 7000 Lb. Stress per Sq. In.
$\frac{3}{4}$	0.7500	0.6057	0.288	1872	2016
$\frac{13}{16}$	0.8125	0.6682	0.351	2282	2457
$\frac{7}{8}$	0.8750	0.7307	0.419	2724	2933
$\frac{15}{16}$	0.9375	0.7932	0.494	3211	3458
1	1.0000	0.8557	0.575	3738	4025
$1\frac{1}{16}$	1.0625	0.9182	0.662	4303	4634
$1\frac{1}{8}$	1.1250	0.9807	0.755	4908	5285
$1\frac{3}{16}$	1.1875	1.0432	0.855	5558	5985
$1\frac{1}{4}$	1.2500	1.1057	0.960	6240	6720
$1\frac{5}{16}$	1.3125	1.1682	1.072	6968	7504
$1\frac{3}{8}$	1.3750	1.2307	1.190	7735	8330
$1\frac{7}{16}$	1.4375	1.2932	1.313	8535	9191
$1\frac{1}{2}$	1.5000	1.3557	1.444	9386	10108

TABLE VII

Allowable Loads on Stay Bolts with V-Threads, 10 Threads per Inch

Outside Diameter of Stay Bolts (In.)		Diameter at Bottom of Thread (In.)	Net Cross-Sectional Area (at Bottom of Thread) (Sq. In.)	Allowable Load at 6500 Lb. Stress, per Sq. In.	Allowable Load at 7000 Lb. Stress per Sq. In.
$1\frac{1}{4}$	1.2500	1.0768	0.911	5921	6377
$1\frac{5}{16}$	1.3125	1.1393	1.019	6623	7133
$1\frac{3}{8}$	1.3750	1.2018	1.134	7371	7938
$1\frac{7}{16}$	1.4375	1.2643	1.255	8157	8785
$1\frac{1}{2}$	1.5000	1.3268	1.382	8983	9674
$1\frac{9}{16}$	1.5625	1.3893	1.515	9847	10605
$1\frac{5}{8}$	1.6250	1.4518	1.655	10757	11585

Load on Stay Bolts. Flat surfaces, other than segments of heads, must be stay-bolted, or stayed by welded or weldless mild steel or wrought-iron head to head or through, or diagonal or crow-foot stays.

The maximum allowable stress per square inch net cross-sectional area of stays and stay bolts should be as given in Tables V, VI, and VII.

Areas of Segments of Heads to be Stayed. The area of a segment of a head to be stayed is the area enclosed by lines drawn 3 inches from the shell and 2 inches from the tubes, as shown in Figs. 47 and 48.

When a flat head has a manhole opening, the flange of which is formed from the solid sheet and turned inward to a depth of not less than twice the thickness of the head, an area 2 inches wide all around the manhole opening, as shown in Fig. 49, may be deducted from the total area of head, including manhole opening, to be stayed.

BOILER TUBES AND FLUES

Spacing of Tubes. Just as the placing of rivet holes in the sheet of a shell boiler reduces the strength of the shell against longitudinal rupture, so does the drilling of holes for the insertion of tubes weaken the plate. In some forms of water-tube boilers the steam and water drums are connected by water tubes which enter the drums along longitudinal lines or parallel with the longitudinal seams. It is obvious that, should the result of such a construction show that the

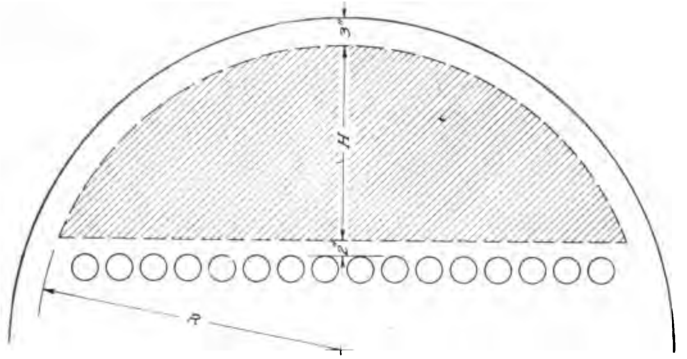


Fig. 47. Method of Determining Net Area of Segment of a Head

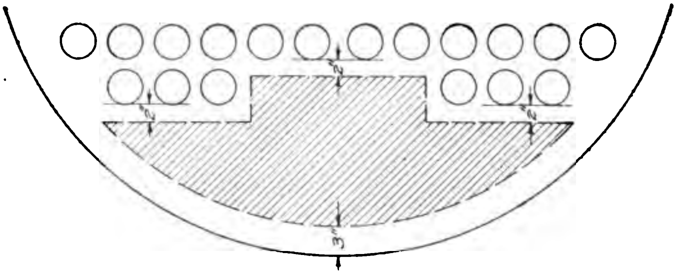


Fig. 48. Method of Determining Net Area of Irregular Segment of a Head

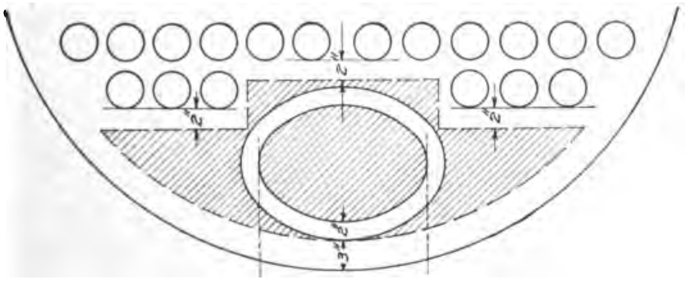


Fig. 49. Method of Determining Net Area of Segment of Head Containing Manhole Opening

shell is weaker along the tube line than along the longitudinal rivet seam, the efficiency of the sheet along the tubes should be used for determining the allowable pressure on the boiler rather than that of the riveted joint. The material remaining between two adjacent tubes expanded into either the cylindrical or the flat part of a boiler construction is termed the *ligament.*

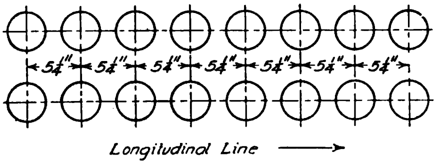


Fig. 50. Diagram of Tube Spacing with Pitch of Holes Equal in Every Row

Efficiency of Ligament. The formulas which follow, as well as examples, are taken from the "Preliminary Report of the Committee of The American Society of Mechanical Engineers to Formulate Standard Specifications for the Construction of Steam Boilers". When a shell or drum is drilled for tube holes in a line parallel to the axis of the shell or drum, the efficiency of the ligament between the tube holes shall be determined as follows:

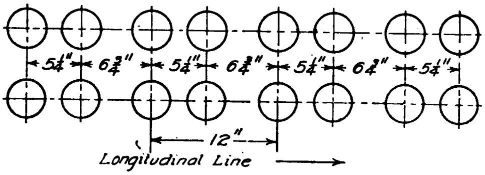


Fig. 51. Diagram of Tube Spacing with Pitch of Holes Unequal in Every Second Row

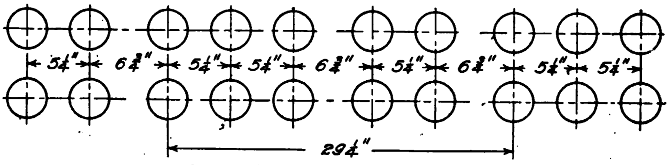


Fig. 52. Diagram of Tube Spacing with Pitch of Holes Varying Every Second and Third Row

1. *When the pitch of the tube holes on every row is equal* (Fig. 50), the formula is

$$\frac{p-d}{p} = \text{efficiency of ligament}$$

in which p is pitch of tube holes in inches, and d is diameter of tube holes in inches.

Example. Pitch of the tube holes in the drum of a water-tube boiler equals 5¼ inches or 5.25 inches. Diameter of tube holes equals 3¼ inches or 3.25 inches.

$$\frac{p-d}{d}=\frac{5.25-3.25}{5.25}=0.38 \text{ efficiency of ligament}$$

2. *When the pitch of tube holes on any one row is not uniform* (Figs. 51 or 52), the formula is

$$\frac{P-nd}{P}=\text{efficiency of ligament}$$

in which P is unit length of ligament in inches; n is number of tube holes in length P; and d is diameter of tube holes in inches.

Examples.

1. $\frac{P-nd}{P}=\frac{12-2\times3.25}{12}=0.458$ efficiency of ligament

2. $\frac{P-nd}{P}=\frac{29.25-5\times3.25}{29.25}=0.461$ efficiency of ligament

3. When a shell or drum is drilled for tube holes in a line diagonal with the axis of the shell or drum, as in Fig. 53, the efficiency of the ligament between the tube holes shall be determined as follows:

$$\frac{P-d}{p}=\text{efficiency of ligament}$$

in which P is diagonal pitch of tube holes in inches; d is diameter of tube holes in inches; and p is distance between rows of tubes, longitudinally.

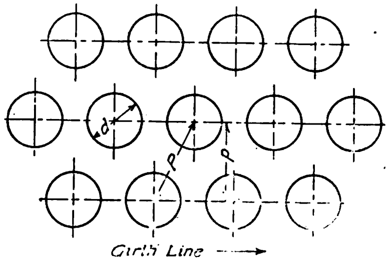


Fig. 53. Diagram of Tube Spacing with Tube Holes in Diagonal Lines

4. Diagonal pitch of tube holes in the drum of a water-tube boiler equals 6.42 inches. Diameter of tube holes equals 4 inches. Distance between rows of tubes, longitudinally equals 5.75 inches.

$$\frac{6.42-4}{5.75}=0.42 \text{ efficiency of ligament}$$

Spacing of Tubes in Flat Water Legs. The construction of stayed box-header water-tube boilers requires that considerable attention be paid to the tube spacing judged from the standpoint of obtaining strength in keeping with the remainder of the boiler. It will be recognized that, should the ligament rupture, the whole boiler head may have to be discarded, as repairs are very difficult

TABLE VIII

Lap-Welded Boiler Tubes

External Diameter Inches	Internal Diameter Inches	Thickness Inches	Internal Circumference Inches	External Circumference Inches	Internal Area Square Inches	External Area Square Inches	Length of Tube per sq. ft. inside Feet	Length of Tube per sq. ft. outside Feet	Weight per Foot-Pounds
1	.856	.072	2.689	3.142	.575	.785	4.460	3.819	.708
1¼	1.106	.072	3.474	3.927	.960	1.227	3.455	3.056	.900
1½	1.334	.083	4.191	4.712	1.396	1.767	2.863	2.547	1.25
1¾	1.560	.095	4.901	5.498	1.911	2.405	2.448	2.183	1.665
2	1.804	.098	5.667	6.283	2.556	3.142	2.118	1.909	1.981
2¼	2.054	.098	6.484	7.069	3.314	3.976	1.850	1.698	2.238
2½	2.283	.109	7.172	7.854	4.094	4.909	1.673	1.528	2.755
2¾	2.533	.109	7.957	8.639	5.039	5.940	1.508	1.390	3.045
3	2.783	.109	8.743	9.425	6.083	7.069	1.373	1.273	3.333
3¼	3.012	.119	9.462	10.210	7.125	8.296	1.268	1.175	3.958
3½	3.262	.119	10.248	10.995	8.357	9.621	1.171	1.091	4.272
3¾	3.512	.119	11.033	11.781	9.687	11.045	1.088	1.018	4.590
4	3.741	.130	11.753	12.566	10.992	12.566	1.023	.955	5.32
4½	4.241	.130	13.323	14.137	14.126	15.904	.901	.849	6.01
5	4.720	.140	14.818	15.708	17.497	19.635	.809	.764	7.226
6	5.699	.151	17.904	18.849	25.509	28.274	.670	.637	9.346
8	7.636	.182	23.989	25.132	45.795	50.265	.500	.478	15.109
10	9.573	.214	30.074	31.416	71.975	78.540	.399	.382	22.190
12	11.542	.229	36.260	37.699	103.749	113.097	.330	.318	28.516
16	15.458	.271	48.562	50.265	187.667	201.062	.247	.238	45.200
20	19.360	.320	60.821	62.832	294.373	314.159	.197	.190	66.765

to make between tubes expanded into a flat plate. The fact that stay bolts are a necessary part of this construction imposes greater difficulties than is the case of expanding tubes in the head of a horizontal tubular boiler. The best boiler makers resort to using tube sheets thicker than seem to be required by calculations of efficiency, thus using high factors of safety for this important part of the construction.

Tube Holes and Ends. Tube holes are drilled full size, or they may be punched not to exceed ½ inch less than full size, and then drilled, reamed, or finished full size with a rotating cutter.

The edges of tube holes should be chamfered to a radius of about $\frac{1}{16}$ inch.

A fire-tube boiler has the ends of the tubes beaded, while water-tube boilers should have the ends of all tubes, suspension tubes, and nipples flared not less than ⅛ inch over the diameter of the tube hole.

The ends of all tubes, suspension tubes, and nipples of water-tube boilers must not project through the tube sheets or headers less than ¼ inch nor more than ½ inch.

When it is necessary to place a fusible plug in a tube, an extra thick tube must be provided for that purpose.

Types of Tubes. Boiler tubes are given the names they would naturally have, so as to be most descriptive, the most usual grades being lap-welded steel, charcoal-iron, hot-rolled seamless steel, and cold-drawn seamless steel. The most commonly used tubes are lap welded because they are the cheapest. All grades are manufactured in the gages most usually demanded; the outside diameter of the tube is used to designate its size.

Lap-welded tubes are formed from a flat plate, the edges of which are upset, then bent around until the thickened edges lap sufficiently. It is then heated successively about 8 inches at a time and welded over a mandrel, which is a cast-iron arm with a slightly convex top, over which the tube is placed. Table VIII gives the dimensions of standard lap-welded tubes.

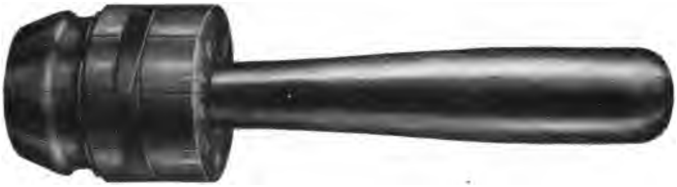


Fig. 54. Type of Prosser Expander
Courtesy of Joseph T. Ryerson and Son, Chicago

Methods of Expanding Tubes. Tubes are fastened to the tube sheets by expanding the metal of the tube into the tube hole. This is done by a tool called an expander, of which there are two common forms.

Prosser Expander. The Prosser expander consists of a steel taper pin and a number of steel segments, held in place by a spring. The outside of the segments have the form to be given to the expanded tube, and the inside is a straight hollow cone, into which the steel taper pin fits, Fig. 54. The segments are forced apart by hammering on the steel pin. In order that the metal of the tube may not be injured, the hammering should be done gradually and carefully, and the expander turned frequently.

Dudgeon Expander. The Dudgeon expander, Fig. 55, has a set of rolls that are forced against the inside of the tube by turning the taper pin. The pin and rolls rotate as the pin is driven, and the rolls gradually expand the tube against the tube plate.

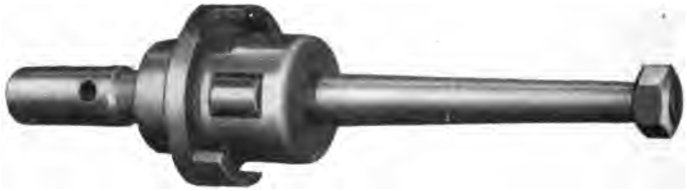


Fig. 55. Type of Dudgeon Expander
Courtesy of Joseph T. Ryerson and Son, Chicago

Fig. 56 shows the effect of using a Prosser type of expander though the distortion of the tube is greatly exaggerated. Fig. 57 shows the effect of using a Dudgeon type of expander.

After the tubes are expanded, the ends are beaded over as shown in Figs. 56 and 57. This adds to the strength of the connection between the tube and tube sheet. Beading over is not usually resorted to when expanding water tubes.

Stay Tubes. Stay tubes are not used as extensively at the present time as they were formerly. They were very common at a time when the holding power of expanded tubes had been experimented on but little. It is now apparent from such tests that the holding power of tubes expanded, as shown in Fig. 56, is more than

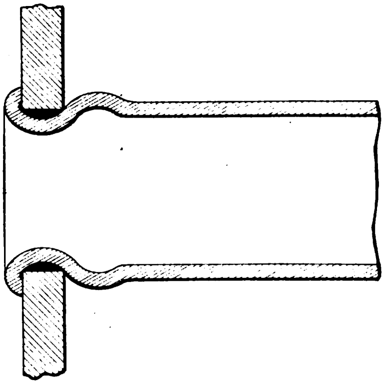


Fig. 56. Section of Prosser Expansion with Distortion Exaggerated

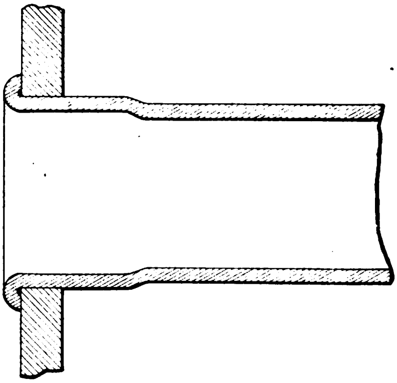


Fig. 57. Dudgeon Expansion

equal to the pressure on the spaces between the tubes of an ordinary tube plate. Stay tubes are simply heavier tubes, with the ends projecting beyond the tube sheet and threaded for shallow nuts. The ends of the tubes are frequently upset or thickened, and screwed into the tube sheet as well. Both forms are shown in Fig. 58.

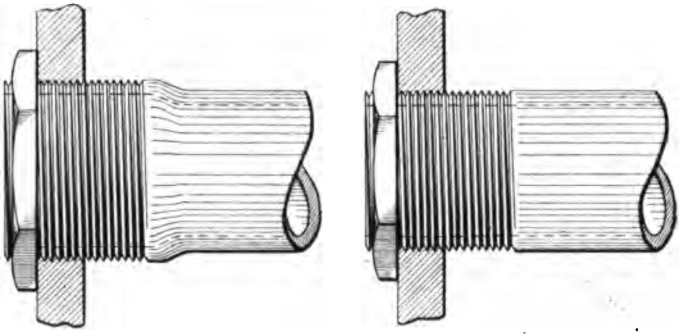


Fig. 58. Stay-Tube Details

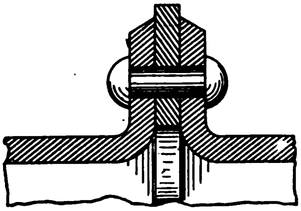


Fig. 59. Adamson Ring Furnace

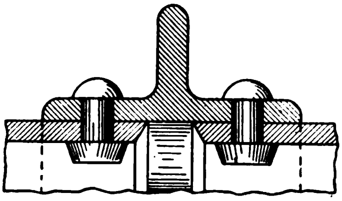


Fig. 60. Furnace Construction Not as Good as Fig. 59

Furnace Flues. Flues which are subjected to external pressure are always cylindrical. Fig. 59 shows a section of the Adamson flue. This was an improvement over the plain furnace, as it is more elastic and allows expansion; the flanged rings also strengthen

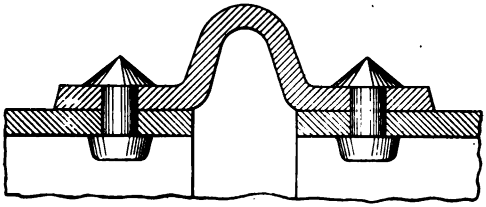


Fig. 61. Furnace Construction Not as Good as Fig. 59

and stiffen it against collapse. The methods of building furnaces shown in Figs. 60 and 61 are not considered as good as the Adamson arrangement. The method shown in Fig. 60 is too rigid, and does not allow expansion, while that of Fig. 61, on the other hand, is elastic; both have the fault of exposing a double thickness of plate and two rows of rivets to the fire at each joint. The ring sections are usually 18 inches in length.

The Morison corrugated flue shown in Fig. 62 is popular and, furthermore, is excellent. There is freedom for expansion throughout its whole length, thereby reducing the stresses on the boiler. The plates should be thick enough to prevent sagging, the thickness usually varying from $\frac{5}{16}$ to $\frac{5}{8}$ inch. Corrugated furnaces are riveted to the rear tube sheet in a return-tubular boiler of the marine type, the end of the furnace being flanged at the front; the head of the boiler is flanged around the opening cut for the furnace, which fits well into the flange.

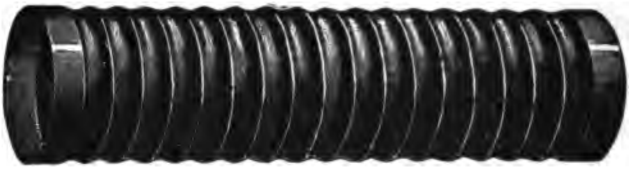


Fig. 62. Morison Boiler Flue
Courtesy of Joseph T. Ryerson and Son, Chicago

BOILER REQUIREMENTS

FACTORS IN DESIGNING BOILERS

General Statement. In designing a steam boiler there are many considerations that must be kept in mind. Among the most important are strength, durability, capacity to furnish the required amount of steam, convenience for cleaning, repairing, and inspection, simplicity in detail, and economy both of running and first cost.

The kind, or type, to be used depends upon the work to be done, the locality, and the available space and preference of the owner. The work to be done is determined by the number and kind of engines, the constancy with which they run, and the pressure. In choosing a boiler for any locality, the purity of the water, the kind of fuel, and the laws which govern inspection and allowable working pressure must be considered. The available space greatly influences the type and sometimes prevents a desirable choice in other particulars. For instance, locomotive and marine boilers must be adapted to small spaces. For stationary boilers, if the floor area is limited, but there is ample height, some type of vertical boiler may be chosen.

Boiler Horsepower. The term "boiler horsepower" is misleading, in that a boiler does not develop power but simply acts as a means for absorbing heat energy in one place and transferring it to a storage medium—the water and steam supplied to the boiler. The power element, when it appears, is found in the power production of the engines in which the steam is used. However, the meaning of the term has become so well understood by frequent use that no special confusion arises. The unit known as one boiler horsepower is the equivalent of the evaporation of 34.5 pounds of water from and at 212 degrees F. Since each pound of water evaporated under the conditions given above represents the absorption of 970.4 British thermal units, one boiler horsepower is equal to the absorption of 33,479 B. t. u. By one boiler horsepower hour is meant the equivalent performance of a boiler horsepower during a period of an hour. This explanation is given so that the difference between engine horsepower and boiler horsepower will be borne in mind, as they are not of equal magnitude, nor of precisely the same physical significance.

General Requirements. A boiler should have:

1. Sufficient area of grate to burn the required amount of fuel.
2. Enough heating surface to absorb the heat of combustion economically.
3. Combustion chamber and flue area large enough to completely burn and carry off the products of combustion.
4. Water space sufficiently large so that a sudden demand will not cause too great a variation in water level.
5. Surface of water large compared to volume, in order that steam may be readily disengaged.
6. Steam space large enough to supply an irregular demand without causing a great change of pressure.
7. Steam outlet large enough to supply steam to the engine without wiredrawing.

If the outlet is not sufficiently large to supply plenty of steam, the demand will be greater than the supply and the steam will be throttled or wiredrawn. that is, it will lose some pressure.

For all common types of boilers, the proportions between the above requisites have been determined by experiment.

Area of Grate. Grates of the same area will burn different quantities of fuel in a given time, depending on the intensity of the draft, the character of the fuel and the fuel bed, and the kind of grate. For hand-fired grates the extreme length is usually from 6 to 7 feet, the width being determined by the width of the furnace flue or boiler setting. For stoker-fired boilers the rate per square foot at which the fuel will burn in a unit time may be very much higher than for hand-fired grates with the same draft. If the mechanical stoker is of a type that removes the refuse accumulation as rapidly as formed, thereby keeping the fuel bed in an open condition, impediments to air flow through the bed are reduced to a minimum and the rate at which the fuel will burn rises. The main factor in determining the rate of combustion for a given furnace construction is the quantity of air forced through the fuel bed. Consequently, since in some types of boilers the grates are restricted in size owing to factors not capable of change, as, for instance, in locomotives, recourse is taken to artificial means for creating an intensity of draft much higher than would be obtained by the use of a chimney.

It has been established as a fundamental truth that boilers absorb practically the same percentage of heat of the amount presented to them without regard to the actual quantity, other factors, such as pressure, remaining the same. Therefore, the way in which the fuel is burned has a great deal more to do with the over-all economy of the boiler unit with its grate and furnace than the boiler or heat absorber itself. Also, it is possible to burn the fuel at so low a rate that the combustion process is inefficient, although the degree of combustion may be practically complete. The area of the grate for a given boiler performance determines then the economy of performance. If too large, certain losses are inevitable for a given draft, and if too small, other losses may occur or the boiler may not deliver enough steam. Out of these facts the following conclusions may be arrived at: If, having selected a certain grate area, it is found that the operating performance is uneconomical, the grate area should be changed, making it either smaller or larger, depending on the steam requirements and draft facilities. It is true that such an expedient is rarely adopted, because, in most instances, there is more than one unit and facilities are offered for operating the units in service according to fair standards by increasing or decreasing the number. A certain degree of elasticity is afforded by the use of boiler dampers which make it possible to change one of the main factors entering into the rate of combustion, namely, draft.

Where mechanical stokers are employed, it is usually best to follow the suggestions of the manufacturers as to sizes, though in such instances they must be apprized of the available draft, furnace construction, and other factors, in order to give intelligent opinions.

Water Evaporation per Pound of Fuel. The number of pounds of water a pound of fuel will evaporate depends upon the heat value of the fuel, the inherent ability of the boiler to absorb heat, the efficiency of the boiler furnace, the cleanliness of the heating surface, and the pressure of operation. It can easily be seen that so many factors, each independent of the others, may, when considered together, result in incorrect conclusions. For purposes of comparison between different installations the actual evaporation is converted into terms of equivalent evaporation for feed water at 212° F. into steam at atmospheric pressure. When a boiler is selected the usual practice is to find out what the results are with fuel of a given character, judging from the results actually obtained in several installations; by the application of good judgment, it is possible to so proportion the grates and the draft facilities that equal or better results are obtained.

The amount of water evaporated per pound of fuel is influenced by the character of the boiler construction, as, for instance, a boiler with good circulation, with its heating surface effective, is sure to give a better evaporative result than one not so well designed. The manner in which the boiler is inclosed, that is, the tightness of the setting, plays a very important part in the boiler performance.

Boiler Rating. The horsepower at which boilers are rated may or may not have any relation to the actual boiler horsepower produced. The horsepower output of a boiler is dependent upon the amount of fuel burned and the efficiency of the boiler and furnace combined. It is quite desirable to rate boilers prior to their actual installation, and engineers have come to establish arbitrary quantities of heating surface as the basis for rating boilers. The areas so selected have varied from time to time until at present it is generally accepted that 10 square feet of heating surface shall be considered one boiler horsepower rating in stationary practice.

Steam Space. It is beginning to be realized that boiler space devoted to steam plays less of a factor in the successful operation of a boiler than was believed to be the case years ago. If the designs are fairly simple, such as in the cylindrical boiler, then the computations which are made regarding steam space are just as valid as ever; but for complicated designs, as in water-tube boilers, the steam space requirements do not apply as rigidly as for boilers with large bodies of water. In these instances it seems more important to pay strict attention to the places where violent ebullition takes place, as, for instance, at the front throat of a horizontal water-tube boiler, than to the actual space devoted to steam. Also the surface from which steam may be liberated plays a larger part in these boiler types than the actual water content. No set rules can be laid down for the complicated designs, but, for cylindrical boilers, an illustration of how to compute steam space will familiarize the student with a number of the problems involved in the subject.

The steam space is frequently designed as some fraction of the interior volume of the boiler, usually about $\frac{1}{3}$. A better way is to design it from the steam consumption of the engine. Suppose the engine uses 30 pounds of steam at 75 pounds pressure per horsepower per hour. The absolute pressure then is 90 pounds (nearly) and the specific volume at that pressure is 4.85 (from steam tables). As steam is being generated at an approximately constant rate, the supply kept on hand need not be great. If the surface for the disengagement of steam is sufficient, the ratio of the steam space to the volume of the cylinder is from 50 : 1 to 150 : 1, depending upon the speed of the engine. Experiment shows that if the steam space is equal to the volume of steam consumed by the engine in 20 seconds, it is sufficient. If the space is equal only to the steam used in 12 seconds, a considerable quantity of water may be carried over with the steam. If the engine is slow speed, that is, less than 60 revolutions per minute, the steam space should be larger.

The volume of the steam space per horsepower will be the number of pounds of steam used per horsepower in 20 seconds, multiplied by its specific volume, or

$$\frac{30\times4.85\times20}{60\times60}=.81 \text{ cu. ft. (nearly) per h.p.}$$

If the engine is of 75 horsepower, the steam space will be

$$.81\times75=60.75 \text{ cu. ft.}$$

Heating Surface. The portion of a boiler that is exposed to the flames and hot gases is called the heating surface. This is made up of the portions of the shell below the brickwork, the exposed ends, and the internal surface of the tubes in fire-tube boilers. If the boiler is of the water-tube type, the exterior surface of the tubes is taken in place of the interior surface.

The ability of heating surface to transmit heat to water depends upon cleanliness, circulation, and temperature of the gases. In designing it is safe to follow proportions of heating surface to grate area in the various types which experience has shown to give the best results. Hand-fired grates, for stationary practice, vary from 45 to 60 square feet of heating surface for each square foot of grate. In other types of boilers, such as locomotives and those using artificial draft, the proportions vary a great deal from these figures. If the boiler is of a type requiring baffles to cause the gases to impinge upon the heating surface, as in water-tube boilers, the effectiveness of the surface may be very much impaired by the construction.

It is evident that some portions of the heating surface of a boiler are more useful than others. For instance, more heat will pass through the crown sheet, as it is in direct line of radiant heat, than through the last few feet of the tubes.

If a cylindrical multitubular boiler is considered divided into equal sections, the section nearest the fire will evaporate more water than the one at the other end, as the gases have a higher temperature at the first section. Suppose the boiler be divided into six sections of equal length, and call the total evaporation 100 per cent. Then the per cent of evaporation per section will be approximately as follows:

Section	1	2	3	4	5	6
Evaporation	47	23	14	8	5	3

If the length of a boiler is increased another section, the evaporation will be increased a little, but the radiating surface is increased at the same time. In case the addition of a section for evaporation causes a loss by radiation nearly equal to the gain in evaporation, it is not economical to add the section on account of the extra cost of the boiler. If forced draft is used, the boiler may be made longer without danger of impairing the draft.

Allowable Pressure. According to Pascal's Law, liquids and gases exert pressure equally in all directions. Steam in a boiler exerts the same pressure on all portions of the shell. As the pressure inside a boiler is considerably greater than the pressure outside (the atmospheric pressure), there is a tendency to burst the shell. This tendency is resisted by the plates of the boiler.

A sphere is the strongest form to resist pressure, for since pressure is equal in all directions, there is a tendency toward enlarging the sphere and not to rupture. But because a sphere has the smallest area for a given volume and a large heating surface is desirable, and also on account of mechanical difficulties, a spherical boiler is never used. The boiler is made cylindrical to obtain greater heating surface, and the loss in strength is made up by staying.

In considering the strength of cylinders, it is usual to divide the rupturing stresses into two classes: those which tend to rupture the cylinder longitudinally, and those which tend to rupture it circumferentially or transversely. The maximum pressure to be allowed on a steel or wrought-iron shell or drum of a boiler shall be determined from: the minimum thickness of the shell plates; the lowest tensile strength stamped on the plates by the plate manufacturer; the efficiency of the longitudinal joint or ligament between the tube holes, whichever is the least; the inside diameter of the outside course; and a factor of safety of not less than 5.

The formula is $\frac{TS \times t \times \%}{R \times FS}$ = maximum allowable working pressure in pounds per square inch, in which TS is tensile strength of shell plates in pounds; t is minimum thickness of shell plates in inches; % is efficiency of longitudinal joint or ligament between tube holes, whichever is the least; R is radius and is one-half the inside diameter of the outside course of the shell or drum; and FS is the lowest factor of safety allowed on boilers in the district or municipality regulating the pressure allowed.

Water-tube boilers are designed to make possible the use of smaller cylindrical shells, the drums being used merely to afford water and steam space through which the boiler proper, namely, the water tubes, conveys the absorbed heat to the boiler outlet. Consequently, for the same thickness of sheets and rivet construction, water-tube boilers can operate at higher pressures than large shell cylindrical boilers, this constituting one of the particular advantages of the type.

Sections. Boiler shells are made up in rings or sections. The length of the sections is often made equal, for convenience in ordering and cutting the plates. The length is limited by the width of plate obtainable and the size of the riveting machine. Shells 16 feet long would probably be made in three sections, but the lengths should be so adjusted as not to bring the ring seam over the hottest part of the fire.

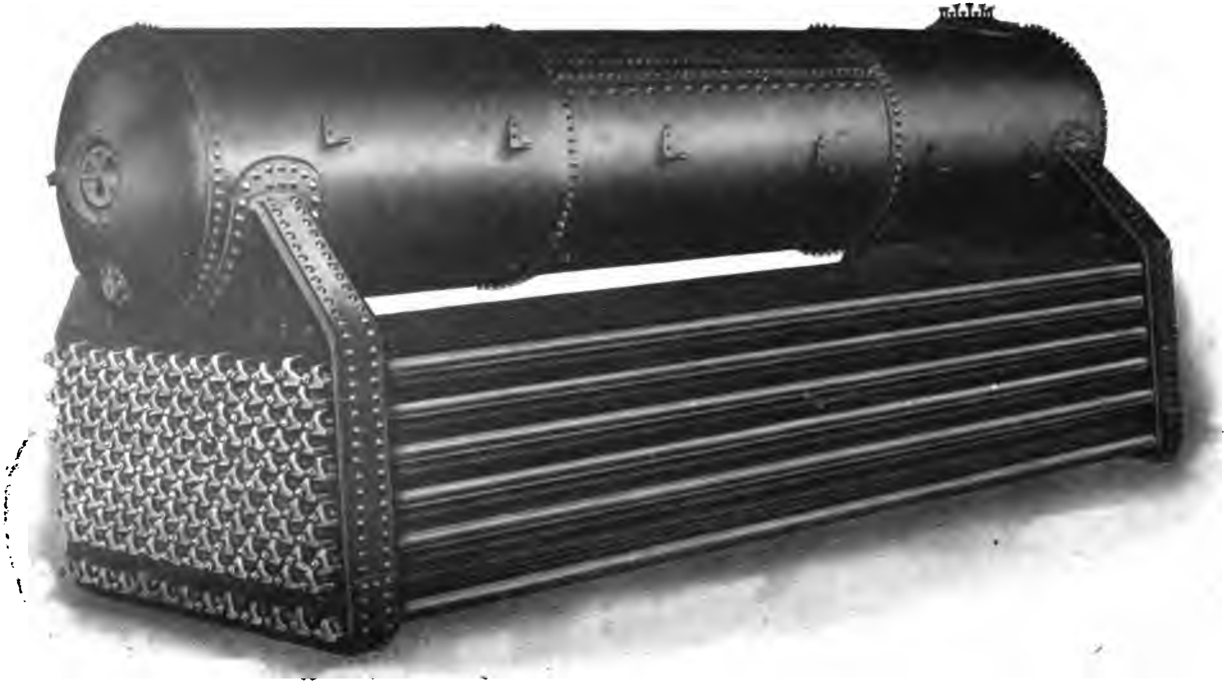
Furnace Flues. The internal pressure at which the boiler shell will rupture can be calculated, but the external pressure which will collapse a flue can be determined only by experiment or experience. External pressure tends to increase any imperfection of shape. For instance, if a flue is slightly oval, external pressure tends to make it more flat; the strongest form to resist external pressure is evidently the circle. When considering the strength of flues, length is very important. If a lap joint is used the flue will not be a true cylinder; for this reason welded or butt joints are preferable.

Attention is again called to the use of the Adamson furnace, Fig. 59, and the corrugated furnace, Fig. 62, as means of overcoming the tendency of furnace flues to collapse under pressure.

Boiler Inspection During Manufacture. When purchasing a boiler, the character of workmanship employed by the manufacturer should be carefully considered. If a factory employs more than one standard of workmanship, then it is highly important, if the best work is desired, to have facilities for knowing that the best standard of the factory is employed on the boilers ordered. All manufacturers can employ the best kind of workmanship, assuming they have the necessary equipment for bending sheets, beveling edges of sheets, power riveting, and flanging.

The only way to be sure that a boiler is receiving the best workmanship is to engage someone to inspect the work as the parts are fabricated. The insurance companies have such inspectors, but they make a practice of inspecting the sheets for defects and rarely are present when the rivet holes are made, the sheets are bent, and the riveting performed. The advantage of having a boiler manufactured in a shop of only one standard, and that the best, is manifest. It is difficult to judge the workmanship of a boiler when once made. If then, as is true, the lives of many people may be jeopardized by poor workmanship in a high-pressure boiler, no effort should be spared to safeguard against a needless hazard, even though considerable additional expense has to be met in order to do so.

The inspection and testing of sheets as stipulated by the engineering societies are extremely important and the data coming from these tests should be carefully inspected by competent persons. Wherever possible, after a boiler is fabricated, it should be tested in the shop. It frequently happens that certain parts of a boiler may be so tested without assembling. After the boiler has been erected in the field, without its setting or covering, a pressure test should be applied. It is customary to apply 50 per cent more pressure than that allowed by the boiler construction and laws. The water should be in the vicinity of 60° to 70° F., and all leaks or "weepings" should be carefully noted, the pressure taken off, and the necessary calking performed. The pressure should then be applied again and repeated until no leakages occur. If the work has been properly done, usually very few leaks appear at the first application of pressure.



HEINE HORIZONTAL WATER-TUBE BOILER WITHOUT SETTING

Courtesy of Heine Safety Boiler Company, St. Louis

TYPES OF BOILERS

INTRODUCTION

Function of a Simple Boiler. A steam boiler is a closed metallic vessel in which steam is generated from water by the application of heat. Only that part of a complete contrivance used for generating steam from water which is employed in the absorption of heat is known as the boiler. All of that portion of the arrangement in which the fuel releases its heat by fire is known as the furnace. Hence, the functions of the furnace and the boiler are exactly opposite; the former generating or liberating heat, and the latter absorbing a part of the heat delivered to it by the furnace.

The purpose of a steam-generating equipment is to convert the available energy of fuel into heat energy carried by steam, so that it may be employed elsewhere, either in an engine in the creation of mechanical energy or used, without conversion, as heat. Where the heat energy of the steam is to be converted into mechanical energy it is necessary to generate the steam at a greater pressure than that of the atmosphere. It follows that the boiler must be made amply strong to withstand the pressure intended, and must also be protected against the consequences of careless, unskillful, and dangerous operating methods.

Boiler Accessories. To operate a boiler safely and economically there must be certain fittings and accessories, some of which are used in the care of the boiler, while others serve to increase its economy. Among the most important attachments and appurtenances are the following:

Feed Pump, or Injector. A feed pump, or injector, with valves, piping, etc., supplies water to the boiler.

Gage Cocks and Water Gage. Gage cocks and glass water gage show the attendant the height of water, or the water level, as it is called, in the boiler.

Pressure Gage. A pressure gage indicates the pressure of steam in the boiler. The pressure is usually measured in pounds per square inch.

Safety Valve. A safety valve allows steam to escape from the boiler when the pressure exceeds a certain fixed amount. This attachment, being a safety device, should be automatic and reliable.

Blow-Off Pipe. A blow-off pipe, with its valves, is used to blow out sediment from the boiler, reduce the amount of water in the boiler, or empty it.

Steam Pipe. A steam pipe, with its valves, conducts the steam from the boiler to the place where it is to be used.

Manholes and Handholes. Manholes and handholes, with covers, are used for making examinations, and when repairing or cleaning.

*Fusible Plugs.** Fusible plugs are designed to give warning when the water level becomes too low.

*High- and Low-Water Alarms.** High- and low-water alarms give warning when the water level is too high or too low.

*Heaters.** A heater is a device for raising the temperature of the feed water to a point as nearly equal as possible to that of the water in the boiler.

Columns, Lugs, or Brackets. Columns, lugs, or brackets are supports for the boiler.

Masonry. Masonry is used for enclosing the boiler and keeping it in position, and in many cases for keeping the hot gases in contact with the heating surface.

Furnace Fittings. Furnace fittings include grate bars, bearer bars, fire doors, ash-pit doors, dead-plates, door-liners, etc.

Damper Frame and Damper. The damper frame and damper are used to control the draft by varying the size of the opening through which the gases are allowed to escape from the boiler setting.

Breeching. The breeching carries the gases from the boiler or its setting to the chimney.

Chimneys. The chimney carries away the waste gases and creates draft.

Tools. Tools include shovels, slice bars, scrapers, tube brushes, soot blowers, gasket molds, etc.

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*Although desirable, they are not absolutely necessary, as a boiler can be successfully operated without them.

CLASSIFICATION

Basis of Classification. The almost endless variety of boilers now in use is due largely to the many conditions under which they are used. Another reason for the numerous forms is the resourcefulness of designing engineers, who, during the last century, have sought to produce, at moderate cost, steam generators which are at once safe, durable, and economical.

A proper grasp of the subject requires that an orderly classification of boilers be attempted. A number of different methods are employed for this purpose, but only those most commonly used are here given. Fortunately, many of the names applied to boilers are sufficiently descriptive, so that little difficulty will be found in locating a boiler in its particular field when once its proper name is known. Much valuable time may be saved, and a better understanding of the subject gained, by selecting one design of boiler to represent a given class. Again, a classification tends to bring out interesting and important features.

All boilers possess one or the other of the following pairs of characteristics:

Fire Tube and Water Tube
Vertical and Horizontal
Stationary and Non-Stationary or Portable
Externally Fired and Internally Fired

There are some designs which employ both characteristics of a pair; for instance, a boiler may have both fire tubes and water tubes; may not be distinctly either vertical or horizontal, but have a position midway between these two.

Boilers are also classified according to the pressure at which they operate, and are then known either as *high-pressure* or *low-pressure* boilers. The pressure at which a boiler is intended to operate determines only how strong the parts must be, and need not affect the selection of the scheme of putting the parts together. Consequently, low-pressure boilers and high-pressure boilers may be exactly alike in external appearance though their construction details and the materials of which they are made may be radically different. Besides, boilers designed to be used at high pressure are frequently used at low pressure. In view of the foregoing, a classification based on pressures alone would not be especially serviceable, even though to boiler manufacturers and engineers the expressions "high-pressure" and "low-pressure" at once bring to mind characteristics of construction peculiar to each group.

Scheme of Classification. The scheme of classification according to *use* and *form* is given as follows:

- According to Use
  - Stationary
    - Early Forms
    - Plain Cylindrical
    - Single Flue, Externally-Fired
    - Flue Boilers
      - Cornish (Single-Flue)
      - Lancashire (Two-Flue)
      - Galloway
    - Multitubular
      - Externally-Fired
      - Internally-Fired (Return-Tubular)
    - Fire-Box Boilers
      - Horizontal
      - Vertical
    - Water-Tube Boilers
      - Straight-Tube
      - Curved-Tube
      - Horizontal
      - Vertical
      - Sectional
      - Non-Sectional
    - Mixed Types
    - Peculiar Forms
  - Locomotive
    - Multitubular Fire-Box (Common Form)
    - Wootten Type
    - Corrugated Furnace
    - Peculiar Forms
  - Marine
    - Early Forms (Box or Rectangular)
    - Scotch or Drum
    - Return-Tubular
    - Through-Tube
    - Water-Tube
      - Curved-Tube
      - Straight-Tube
      - Sectional
      - Non-Sectional
    - Launch Boilers
- According to Form
  - Early Forms
  - Flue
    - Cornish (Single-Flue)
    - Lancashire (Two-Flue)
    - Galloway
    - Single Flue (Externally-Fired)
  - Fire-Tube (Multitubular)
    - Horizontal (Common Form)
    - Vertical
    - Return-Tubular
    - Through-Tube
    - Fire-Box
    - Peculiar Forms
  - Water-Tube
    - Horizontal
      - Straight-Tube
        - Sectional
        - Non-Sectional
      - Curved-Tube
    - Vertical
      - Straight-Tube
      - Curved-Tube
    - Peculiar Forms
  - Mixed Types

Definitions. The following definitions should be remembered:

Fire-Tube Boiler. A fire-tube boiler is one having the heating surface composed largely of tubes which are surrounded by water, the hot gases passing through them.

Water-Tube Boiler. A water-tube boiler is also composed of tubes, but in this case the water flows through the tubes, while the hot gases pass around them.

Sectional Boiler. In a sectional boiler the tubes and corresponding headers form comparatively small units. Each unit is complete in itself; that is, it is in communication with a steam and water drum but is independent of the other units.

Non-Sectional Boiler. A non-sectional boiler is one having all the tubes in communication with one another; in other words, all or nearly all the tubes are expanded into a common header or drum. The boiler is not made up of units.

Single-Tube Boiler. A single-tube boiler is one which is made up of single tubes.

Double-Tube Boiler. A double-tube boiler has a small tube inside of the regular tube and concentric with it.

Externally-Fired Boiler. A boiler is externally fired when the furnace walls do not form a part of the boiler-heating surface but are built out of fire brick or other refractory material.

Internally-Fired Boiler. In the internally-fired boiler the furnace walls are a part of the boiler-heating surface as well as a part of the furnace; the Scotch marine is a good example.

Fire-Box Boiler. A fire-box boiler is one type of internally-fired boilers in which the furnace walls are flat or nearly so. The locomotive boiler is the best example.

EARLY FORMS OF BOILERS

The earliest boilers of which we have reliable record were spherical. They were of cast iron and set in brickwork. It was customary to set this type of boiler with the fire underneath and construct flues in the brickwork to conduct the hot gases around the boiler just below the water level. The hot gases passed entirely around the boiler before escaping to the chimney.

Haystack Boiler. The next form to be generally used was that invented by Newcomen in 1711. On account of its peculiar shape it was called the "Haystack" or "Balloon" boiler. It was of wrought iron and had a hemispherical top and arched bottom. The fire was placed underneath the arched portion, the hot gases surrounding the lower part of the boiler. An improved form of the Haystack boiler is shown in Fig. 1. Smeaton placed the fire inside the shell and arranged internal flues for conducting the hot gases to the chimney. This arrangement increased the heating surface and, consequently, the economy of the boiler.

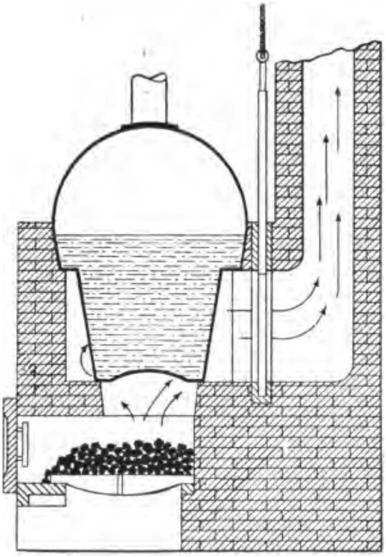


Fig. 1. The Haystack Boiler

Wagon Boiler. To increase the heating surface still more, James Watt introduced his "Wagon" boiler, Fig. 2. The top was semicylindrical and the sides curved inward. The curved plates assisted in the formation of side flues. The hot gases passed from the grate beneath the boiler to the rear, through the left-hand flue to the front, then through the right-hand flue to the rear, and thence to the chimney. This was called the "wheel draft" because the gases passed entirely around the boiler. In the large sizes a flue was placed in the boiler. The products of combustion returned through this flue to the front after passing under the boiler to the rear, as in the small sizes. On issuing from the flue at the front, the gases divided and passed to the chimney at the rear by means of the flues in the brickwork. This form of draft was called the "split draft".

Watt used a column of water in the vertical feed pipe as a pressure gage; the rise and fall of this column also controlled the damper. The feed was regulated by a float.

Although such boilers as the Haystack, Wagon, and others were fairly satisfactory at the time they were invented, they could not withstand the higher pressures which soon became common.

About the beginning of the nineteenth century the cylindrical boiler was introduced. The earliest forms were the plain cylindrical boiler and the "egg-end" boiler. The difference was in the form of the ends—those of the former were flat and of cast iron, while the ends of the latter were hemispherical and made of wrought iron. The egg-end boiler required no staying or bracing because its form is, with the exception of a sphere, the strongest to resist internal pressure.

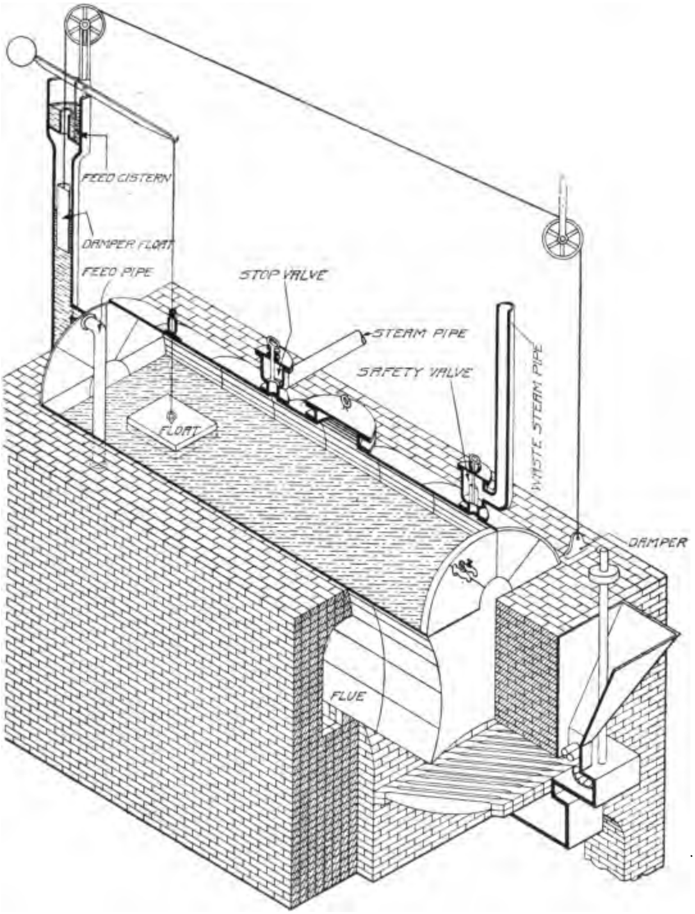


Fig 2. Diagrammatic Sketch of Watt's "Wagon" Boiler

Cylindrical Boilers. The cylindrical boiler consists of a shell of wrought-iron boiler plate and ends of the same material or of cast iron. It is set in brickwork as shown in Fig. 3. The boiler is about two-thirds filled with water, the remaining third forming the steam space. To collect and store the steam as it rises from the water a steam dome is added. The steam pipe is attached to the dome, to which the safety valve is connected also. The hot gases from the fire pass under the boiler to the rear and then to the chimney.

The heating surface of this type is small for a given diameter unless the boiler is very long. As all sediment collects in the bottom where the heat is most intense, the plates are likely to be burned. Sediment and scale being poor conductors of heat, the heat remains in the plates and burns them instead of passing to the water.

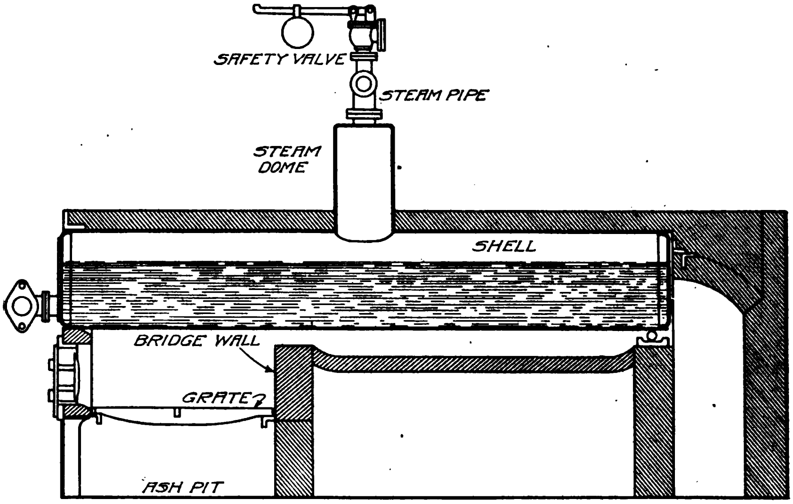


Fig. 3. Cylindrical Boiler and Setting

The disadvantages—the small heating surface and the collection of sediment—do not seem so serious when the simplicity, durability, and strength of construction, and the ease of cleaning and making repairs are considered.

The plain cylindrical boiler is adapted for mining districts and other places where fuel is abundant and where skilled boilermakers are not readily found. This boiler is made very long to obtain the required heating surface, the length sometimes exceeding fifty feet. Some of these boilers are still in use where relatively low operating pressures are allowed, but they are being rapidly displaced.

MODERN FLUE BOILERS

In order to get the necessary heating surface in the cylindrical boiler without making it excessively long, it was made with an internal flue through which the hot gases passed to the chimney. This flue was quite large and extended from end to end of the boiler. In the United States, Oliver Evans used this type as early as 1800. In England, it led to the internally-fired flue boilers which were, and are still, extensively used.

CORNISH BOILER

Horizontal—Single-Flue—Internally-Fired. When it was found that a large proportion of the total heat of combustion was lost by radiation and air infiltration, a Cornish engineer named Trevithick conceived the idea of placing the fire inside of a large internal flue. The type he introduced is known as the Cornish boiler.

Path of Hot Gases. The products of combustion pass from the fire on the grate bars *C*, Fig. 4, through

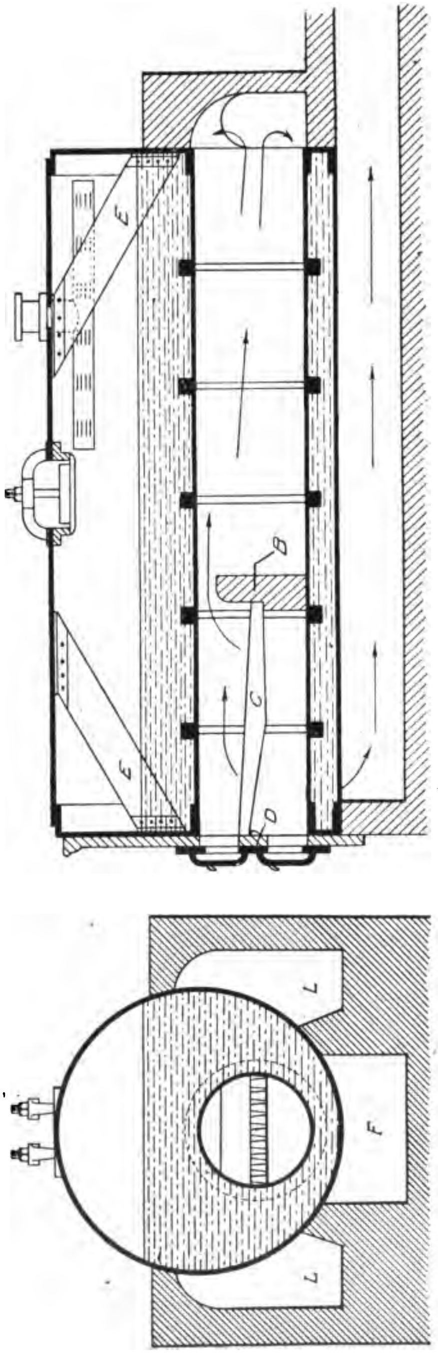


Fig. 4. Transverse and Longitudinal Section of Cornish Boiler

the flue to its back end, where they divide and return to the front end by means of the lateral flues *L* in the brickwork. At the front the hot gases pass downward and, uniting, pass through the flue *F* in contact with the bottom of the boiler. On leaving the boiler they go to the chimney. This arrangement of flues reduces the temperature of the gases before they come in contact with the bottom of the boiler, where sediment collects. The grate bars rest on the dead plate *D* at one end and on the bridge *B* at the other, Fig. 4. If made in two lengths, as is often the case, they are supported at the center by a cross bearer. The bridge is built of fire brick, and the external flues are lined with fire brick. The heads are stayed to the shell by gusset stays *E E*.

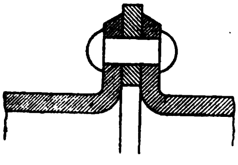


Fig. 5. Adamson Ring Furnace Construction

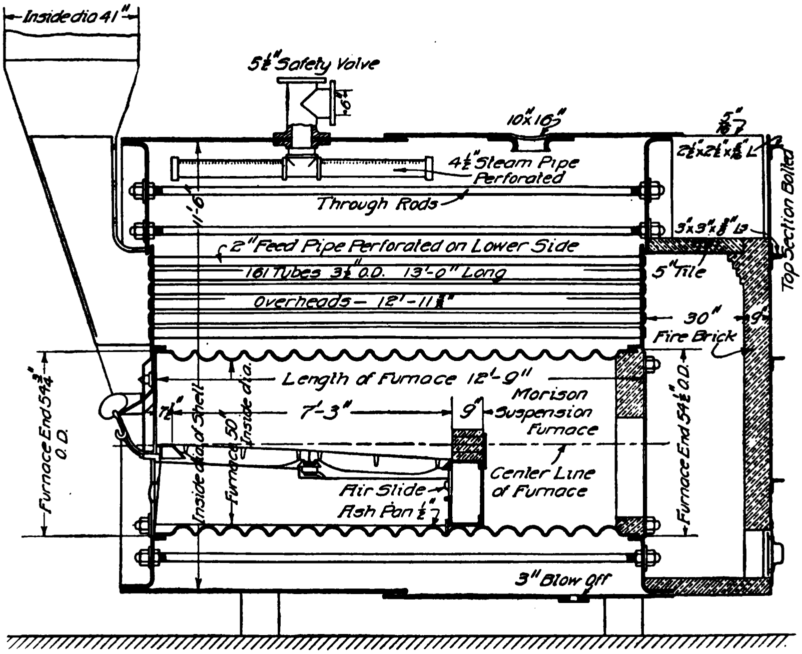


Fig. 6. Section of Morison Boiler Showing Corrugated Flue
Courtesy of Joseph T. Ryerson & Son, Chicago

Taking Care of Expansion. The large internal flue is the hottest part of the boiler because it contains the fire. For this reason the flue has greater linear expansion than the shell, and, when the flue is a plain cylinder, the increase in length causes the ends to bulge. When the boiler is cold, the flue returns to its normal length. This lengthening and shortening will soon loosen the flue at the ends. To overcome this, the flue is sometimes made up of several short rings flanged at the ends and joined by being riveted to a plain ring. This construction is shown in section in Fig. 4. Another method is shown in section in Fig. 5. The plain rings are riveted to the curved rings; the latter take up the expansion, slightly increase the heating surface, and strengthen the flue against external pressure. This form is known as the "Adamson Ring". The same results may be obtained by the use of the corrugated flue, one form of which is shown in Fig. 6. The corrugated flue has many advantages over the devices shown in Figs. 4 and 5; it is frequently used in internally-fired boilers.

LANCASHIRE BOILER

Horizontal—Two-Flue—Internally-Fired. It can be proved, both by experiment and by calculation, that with a given thickness of material cylinders of large diameter cannot withstand as much pressure as smaller ones. For this reason, and on account of the short distance a fireman can throw coal accurately, the Cornish boiler is suitable for small powers only. If it is made too large, the flue is likely to collapse; but, on the other hand, if the diameter of the flue is too small, the grate will be insufficient in area. When this form of boiler is to be used in a large size, it is modified by using two flues instead of one. This is called the Lancashire boiler. It is like the Cornish except that it has two flues and, of course, two furnaces.

The flues are sometimes continued separately to the end. If they merge into one large flue, which forms the combustion chamber, it is called the "breeches-flued" or duplex furnace boiler. These furnaces are fired alternately; the unburned gases set free from the freshly-fired coal are burned on meeting the hot gases from the incandescent coal of the other furnace. This arrangement aids in preventing the escape of partly burned gases.

The main disadvantage in the design of the Lancashire boiler is the difficulty in finding room for the two flues without greatly increasing the diameter of the boiler. Also, the small furnace space is unfavorable to the complete combustion of the gases, the space for mixing and burning being restricted. The combustion chamber of the breeches-flued boiler increases the space, but the construction at the junction of the two flues is weak and has been responsible for many explosions.

GALLOWAY BOILER

Horizontal — Two-Flue — Internally-Fired — Galloway Tubes. Another boiler of the same general form is the Galloway, shown in Figs. 7, 8, and 9. It was developed with a view to overcoming the shortcomings of the Lancashire boiler by providing obstructions in the flues to cause an intimate mixture of the gases of combustion, at the same time adding efficient heating surface; the cross flues also serve to create a circulation of water around the bottoms of the main flues, thus overcoming a serious objection to the Lancashire boiler, which is deficient in this respect.

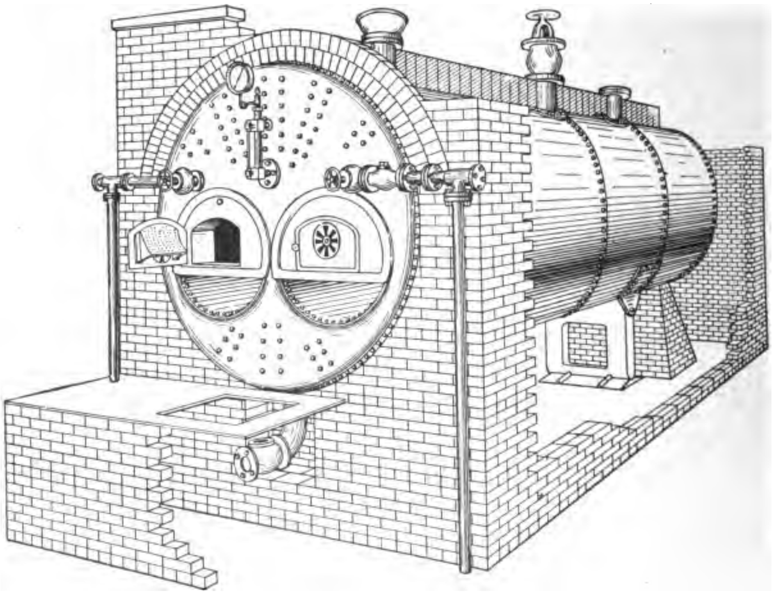


Fig. 7. Galloway Boiler. Brick Setting Partially Removed

Two Types. There are two different forms of Galloway boilers: those having two distinct flues, and those having two furnaces which unite into one large flue. The earlier form has two flues extending the length of the boiler; behind the furnace short tubes, as shown in Fig. 8, cross the flues.

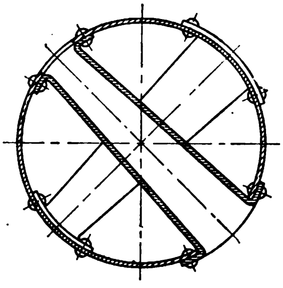


Fig. 8. Cross Flues in Two-Flue Galloway Boiler

In the later form, the two flues merge into one large flue of the shape shown in Fig. 9. This flue has corrugated sides and the conical tubes are staggered, thus insuring a thorough breaking up of the currents of hot gases. The tubes are made conical to facilitate removal for repairs. The shape of the tube also permits the water to expand on being heated, and the particles to rise vertically without disturbing the water on the heating surfaces above. The conical tubes are more generally riveted than welded because the removal of a tube that is welded leaves a large hole in the flue. This form of flue boiler marked a big advance over the earlier forms, partly due to the inherent improvements and partly because the manufacturers realized the importance of related features, such as skillful firing and providing adequate draft. Many of these boilers are still in use in America as well as in England.

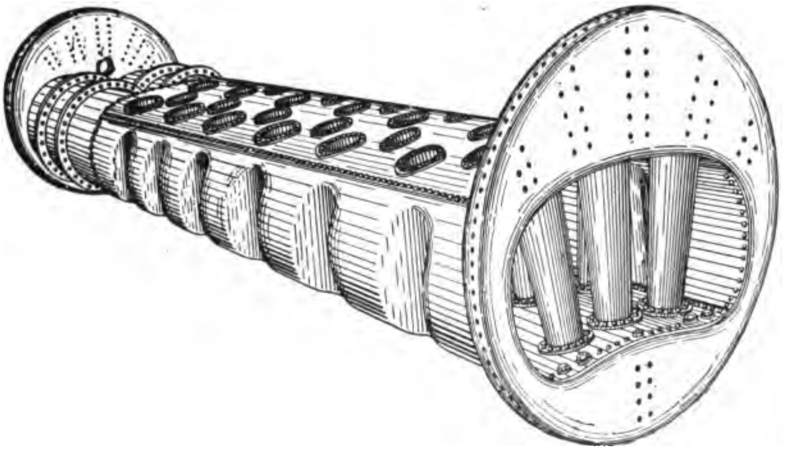


Fig. 9. Later Form of Galloway Flue

FIRE-TUBE BOILERS

COMMON HORIZONTAL TYPE

Single-Flue Boiler. *Single Fire Tube—Externally-Fired.* In the Cornish, Lancashire, and Galloway boilers, the large internal flue served as a fire box. There was, however, a flue boiler having the fire external to the shell. The boiler shown in Fig. 10 resembles the plain cylindrical boiler, illustrated by Fig. 3, both in appearance and setting, but it has one or more large flues extending from end to end. This increases the heating surface to such an extent that the boiler can be considerably shorter than the plain cylindrical boiler. Note that the gases leave the setting on the front end.

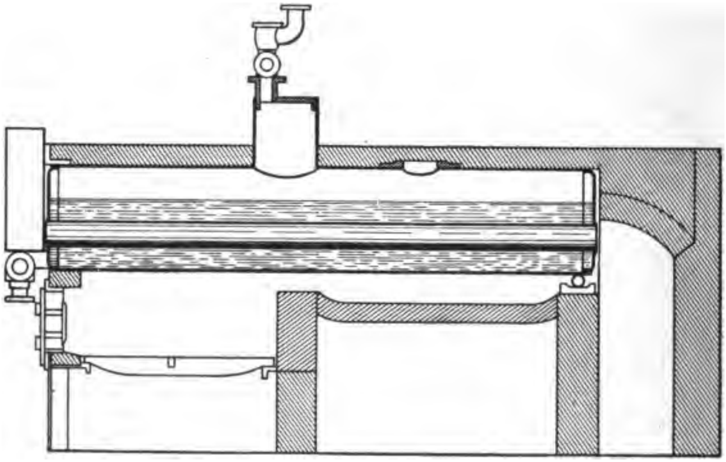


Fig. 10. Section of Cylindrical Flue Boiler

Multitubular Boiler. *Many Small Fire Tubes—Externally-Fired.* When engineers found that the internal flue was an advantage, they soon added more tubes. As the number increased, the size diminished until they became of the size used at present. This is a brief statement of the development of the multitubular boiler. For many years this type of boiler has been commonly used for stationary work, and, although other types possess advantages for certain conditions, it is still considered economical, reliable, easily handled, and safe, if constructed of good material and operated with care and intelligence, in small and medium-sized plants operated at moderate pressures.

Description. Figs. 11 to 14 are selected to illustrate this boiler. The boiler without the brick setting is shown in Fig. 11. It consists of a steel cylindrical shell and numerous small tubes extending from end to end. These tubes are 3 to 4 inches in diameter and are fastened to the two ends, called tube sheets, by expanding the tubes into the sheet and beading them over on the outside. The shell is made of steel plates $\frac{1}{4}$ to $\frac{3}{4}$ inch in thickness, depending on the diameter and pressure. At the front, the shell plates extend beyond the tube sheet and are cut away to allow the waste gases to enter the uptake. About one-third the volume of the boiler is occupied by the steam; the other two-thirds is filled with water and tubes. The water line is a short distance (from 3 to 8 inches) above the top row of tubes.

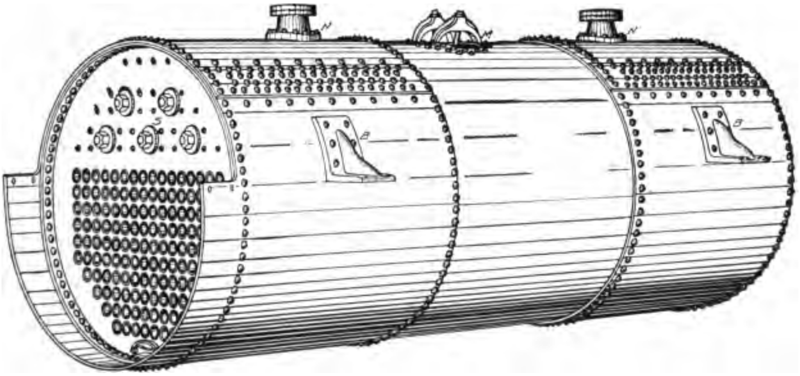


Fig. 11. Multitubular Boiler without Its Setting

The flat ends are prevented from bulging by stays, which may be of the form shown in Fig. 12, or they may be diagonal stays. The through stays are fastened to the tube plates by means of nuts and washers as shown at *S* in Fig. 11, and also in Fig. 12. Below the water level, the end plate is stayed by the tubes. This type of boiler may be supported by brackets *B* riveted to the shell or by means of beams and columns, as shown in Fig. 14. The front bracket is often fixed in the side wall, but the rear bracket should be placed on rollers. This will prevent the straining of the plates during expansion and contraction. A small space must be left between the rear tube sheet and the brick wall to allow for expansion.

The boiler shown in Fig. 11 has two steam nozzles *N*. If the boiler has a dome, the steam nozzle is placed either at or near the top of the dome. The feed pipe may enter either at the front or at the rear. It frequently terminates in a perforated pipe below the water line. The blow-off pipe is at the rear of the boiler, as shown in Fig. 13. A valve, called the blow-off valve, regulates the flow and may be opened to blow out sediment and detached scale. The boiler is usually set with a slight inclination toward the rear so that mud and detached scale may collect near the blow-off pipe.

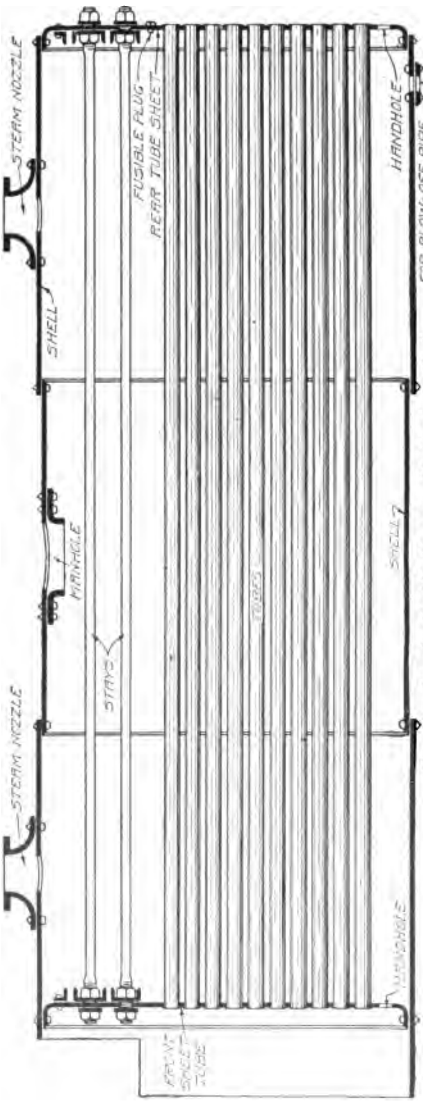
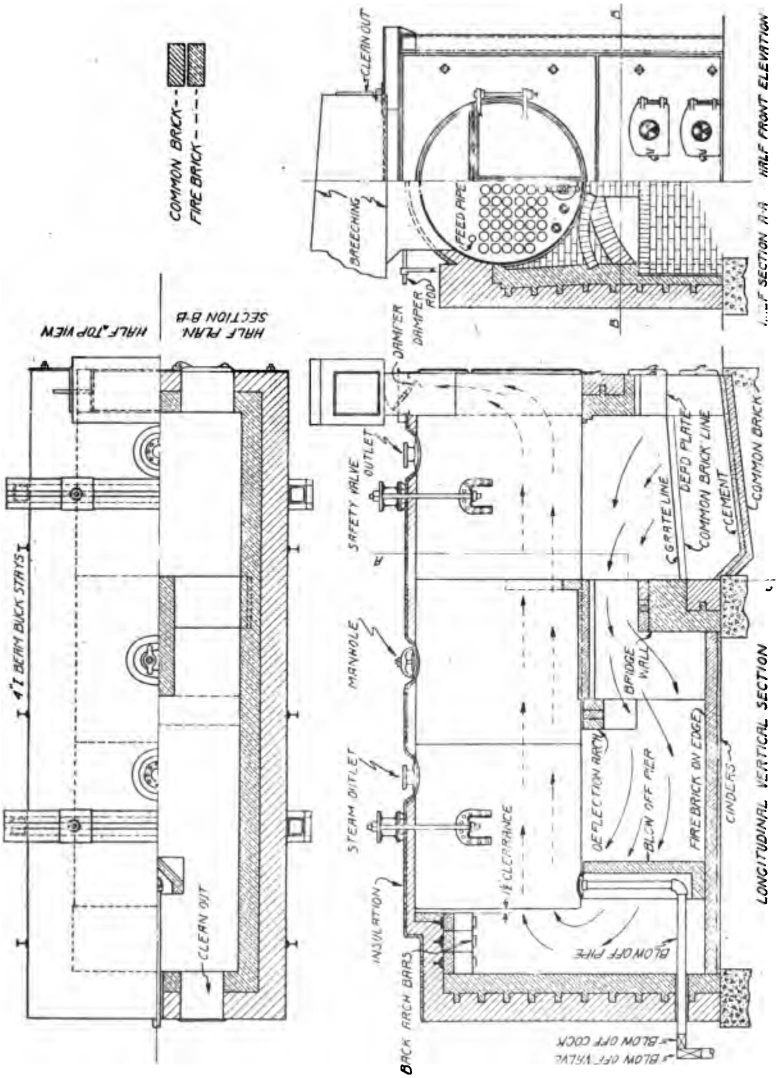


Fig. 12. Longitudinal Section of a Multitubular Boiler

Cleaning and Repairing. In order that the boiler may be entered for cleaning or repairs, it is provided with manholes and handholes. Fig. 11 shows a manhole *M* at the top near the middle and a handhole near the bottom of the front tube sheet. Handholes may be put in wherever desired, but manholes can be located only where the arrangement of stays and tubes will permit a space large enough for the entrance of a man. Manholes and handholes are made elliptical in shape. The former are about 11 inches by 15 inches in size, and the latter about 4 inches by 6 inches.

Heating Surface. The heating surface is the surface exposed to hot gases. In this type, the heating surface is made up of about half the shell, the tubes, and about two-thirds of the rear tube sheet. In general, all the heating surface is below the water line.



Figs. 13 and 14. Plan, Longitudinal Section, and Cross Section of Multitubular Boiler, Showing Setting Features

Form of Setting. The complete multitubular boiler is shown in its brick setting in Fig. 14, and a longitudinal section of the setting in Fig. 13. The brick setting consists of brick laid in cement or mortar. The bridge and the portions of the furnace exposed to the fire are lined with fire brick, laid in fire-clay mortar. The bridge is built at the rear of the grate and forms a support for the grate bars; it also directs the flames upward. The arrows show the direction of the flow of hot gases. The furnace is formed by the bridge, the side walls, and the lower part of the boiler front. The boiler front is usually of cast iron with the lower part lined with fire brick. The front has doors which lead to the furnace, ash pit, and smoke box. The space below the grate is called the ash pit, and through its doors ashes are removed and a large portion of the air for combustion enters. Both the fire doors and the ash-pit doors have draft plates, or grids, to regulate the supply of air. The doors to the smoke box give access to the tubes for cleaning and repairs.

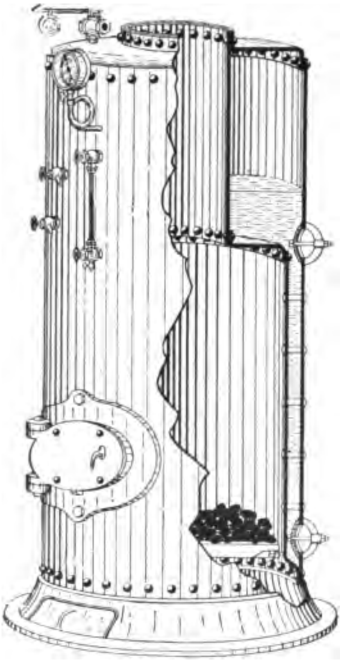


Fig. 15. Vertical Fire-Box Boiler

VERTICAL TYPE

Upright boilers are used when floor space is valuable and there is sufficient height. Small sizes are used for pile driving, supplying steam for pumps and similar work, and in hoisting engines; large sizes are used if it is necessary to have a powerful battery in a small space. In general, they are not so economical as horizontal multitubular boilers unless they are carefully designed and of considerable height. If the tubes are short, the hot gases escape before they give up much of their heat.

Single-Tube Boiler. One of the simplest forms of upright boiler is shown in Fig. 15. It has a cylindrical shell with a large fire box at its lower end. This fire box is formed by the inner cylinder, which is fastened to the outer shell by short screw stay bolts as shown. A flanged ring connects the fire box with a large flue which conducts the hot gases away. The necessary handholes, gages, safety valves, etc., are provided. This form is not economical but is used on account of the little attention required.

Multitubular Boiler. More economical forms of the small upright boiler are illustrated in Figs. 16 and 17. The boiler shown in Fig. 16 is a common form, externally being like the boiler represented by Fig. 15, but having a somewhat different inside construction. It resembles a multitubular boiler placed on end. The fire box is made of an inner cylinder stayed to the outer. The top of the fire box, called the lower tube sheet, is connected to the upper head by tubes, through which the hot gases pass to the smoke pipe. It will be readily seen from Fig. 16 that the upper ends of the tubes are surrounded by steam while the lower portions are covered with water. As steam is a poor conductor of heat, the ends of these tubes are liable to injury from overheating.

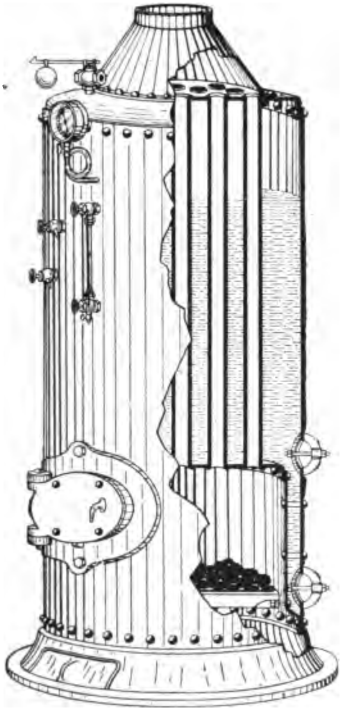


Fig. 16. Vertical Multitubular Boiler

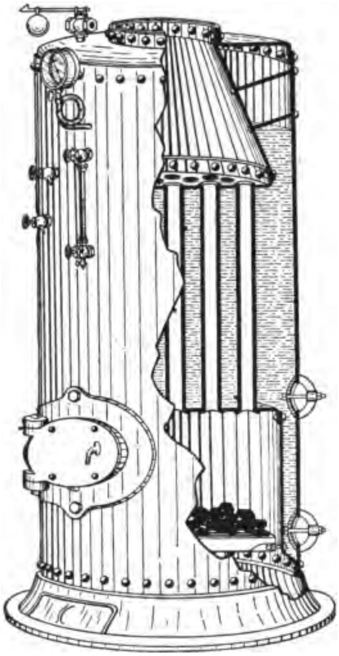


Fig. 17. Vertical Multitubular Boiler with Upper Ends of Tubes Below Water Line

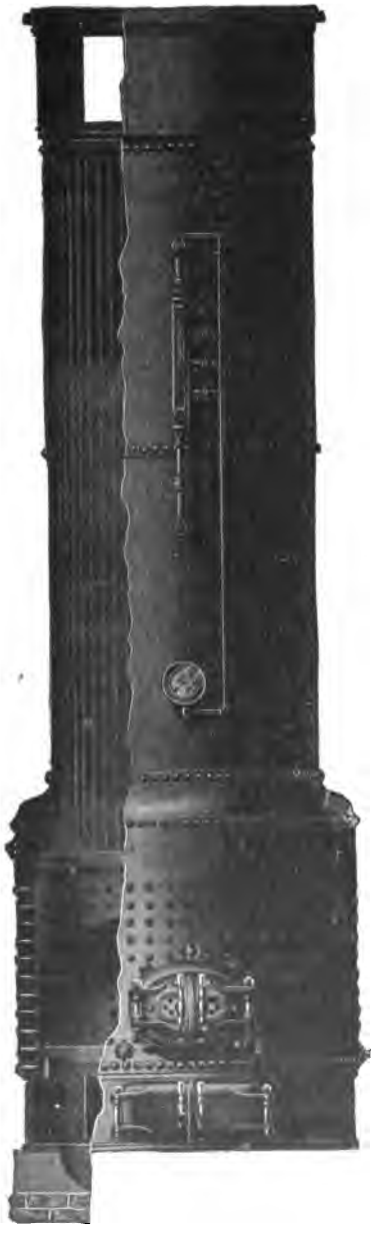


Fig. 18. Manning Boiler
Courtesy of The Bigelow Company

In the class of boiler shown in Fig. 17 the upper ends of the tubes are below the water level, thus avoiding the fault just described in connection with Fig. 16. The upper tube sheet is submerged, and is flanged and riveted to the frustrum of the cone which forms the smoke box. The chief defect in this boiler is that the lower part of the cone is often placed too near the shell; this is done to admit more tubes. This construction restricts the space so much that there is not sufficient room for the steam to rise as it is formed on the tubes. The cone, which is subjected to external steam pressure, is likely to be weak and should be carefully stayed.

These small upright boilers require no brick setting, as the fire box is within the boiler and the cast-iron foundation forms the ash pit.

Manning Boiler. The Manning boiler is illustrated in Fig. 18. It is, in general, similar to the upright boiler shown in Fig. 16, but in order to get a large heating surface, it is made 20 to 30 feet high. At the lower portion, the shell is of greater diameter than at the top in order to provide a large grate area. The inner fire box is stayed to the shell by screw stay bolts. As the fire box is surrounded by water and there are many long tubes, there is a large heating surface. The tubes are arranged in concentric circles with a space for circulation in the middle.

The external fire box is joined to the shell by a double-flanged ring as shown in Fig. 19; or by the cone-shaped section as illustrated in Fig. 20. The top edge of the internal fire box is riveted to the lower tube sheet, which is flanged. The bottom of the inner fire box is connected to the outer shell by a welded ring, shown in section in Figs. 19 and 20, called the foundation ring. The water space between the inner and outer fire-box plates, called the water leg, should be large.

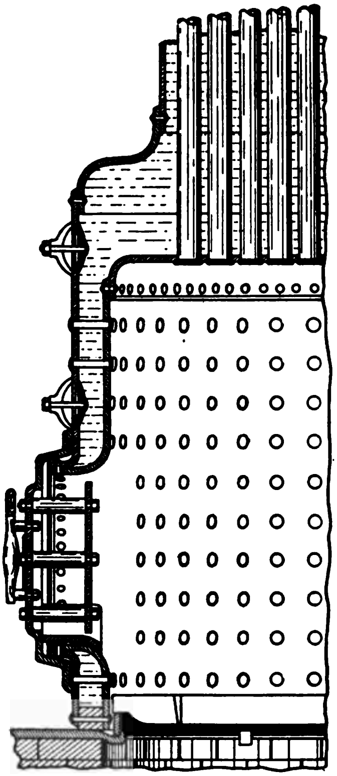


Fig. 19. Manning Boiler Details

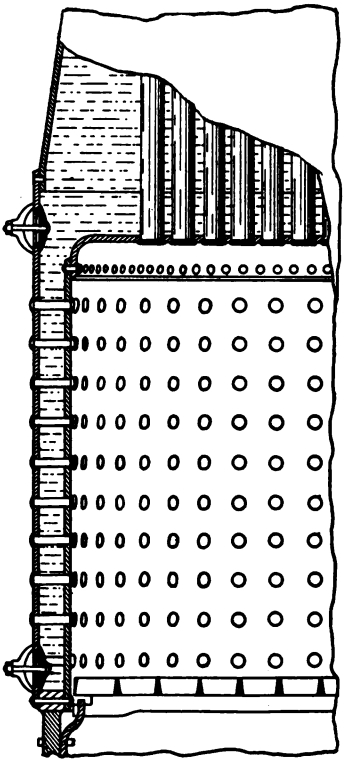


Fig. 20. Manning Boiler Details

This boiler is cleaned by means of handholes. They are placed in the shell plates near the lower tube sheet, in the external fire box just over the furnace door, and at the bottom near the foundation ring. As there are no manholes for cleaning, the boiler is suited to good feed water only.

The feed pipe enters the shell at the side near the middle of the water space, and extends across the boiler; it is perforated to distribute the water.

The heating surface consists of the inside of the fire box and the tubes up to the water level, and the tube sheet. That part of the tubes above the water line is the superheating surface; that is, the heat from the gases passes through the metal of the tubes to the steam, thus raising its temperature without raising its pressure. Steam heated under these conditions is called "superheated steam". In small vertical boilers this superheating surface is not desirable because the work of the small boiler does not require superheated steam and the tubes are likely to be burned by the intense heat. With the long tubes of the Manning, the gases are not as hot when they reach the top, and as this boiler is built in fairly large sizes, 200 horsepower being common, the engines supplied are built for economy, and require dry if not superheated steam.

INTERNALLY-FIRED MARINE TYPE

RETURN-TUBULAR BOILERS

Horizontal—Many Small Fire Tubes. The boilers hitherto described are used mainly for stationary work, the exceptions being so few that they need not be even mentioned. However, there is another modification of the fire-tube boiler which is now extensively used in marine work. The parts of the return-tubular boiler are essentially the same as those of flue boilers (Cornish and Lancashire) and of the multitubular boiler. They are, however, arranged differently in order to be used on board ship.

Earliest Forms. The earliest forms of marine boilers, working with pressures of 15 to 30 pounds per square inch, were square or box-shaped. They were economical and of convenient form for ships. When higher steam pressures became necessary, the flat surfaces required so much staying that they were abandoned and the cylindrical type was introduced, as this form is the best of the practical shapes to resist internal pressure. The cylindrical form may not be as conveniently stowed aboard ship, but it will stand much higher pressures. The cylindrical marine boiler is frequently built for 200 pounds per square inch working pressure.

Single-Ended Single-Flue Type. The single-ended return-tubular boiler, shown in Fig. 21, combines the internal furnace flue of the Cornish type and the numerous small fire tubes of the multi-tubular. The cylindrical shell is made up of plates riveted together and to the flat ends of the boiler, which are flanged to fit the shell.

Furnace. The furnace is cylindrical, 3 to 4 feet in diameter, and about 7 feet in length. The front end of the furnace flue is riveted to the front end plate, which is flanged for the purpose. The back end is riveted to the combustion chamber plates. Formerly, the flue was a plain cylinder, but as a plain cylinder, unless of small diameter, cannot stand much external pressure, it soon became necessary to strengthen it. This was done by means of the curved ring shown in Fig. 5 and other methods; at present the corrugated flue is used, one form being shown in Fig. 6.

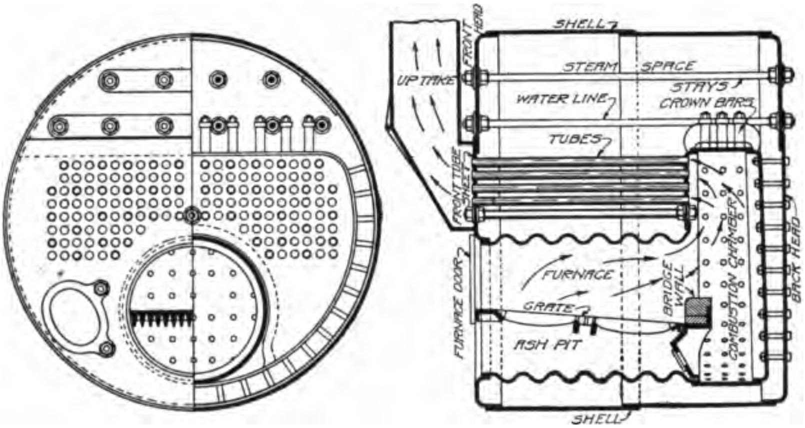


Fig. 21. Return-Tubular Boiler. Early Form

Grate. The grate is placed at about the center of the height of the furnace flue; the space above this grate is occupied by the fire and hot gases, while below is the ash pit. As will be seen from the arrows in Fig. 21, the hot gases fill the space above the fire, the combustion chamber, the tubes, and the uptake.

Combustion Chamber. The combustion chamber, in which the products of combustion are burned, is formed of flat and curved plates flanged at the edges and riveted together. The shape of the plates is shown in Fig. 21, which is a sectional view of a single-ended marine boiler. The back tube sheet forms the front of the combustion chamber. The space around the tubes, furnace flue, and combustion chamber is filled with water, the water level being 6 to 8 inches above the top row of tubes. The space above the water level is called the steam space.

Stay Rods. As the return-tubular boiler has several flat surfaces, this type requires careful staying. The flat ends above the water level are prevented from bulging by long stay rods similar to those in the multitubular type. Below the water level, the furnace flue and the tubes aid in holding the flat plates in position. Moreover, a few of the tubes, shown by the heavier circles in Fig. 21, are made thicker so that a thread may be cut on the ends, which are screwed into the tube sheets and held by thin nuts. The combustion chamber plates are stayed to the rear end plate and the shell by short screw stay bolts. The flat top of the combustion chamber is supported by girders or crown bars.

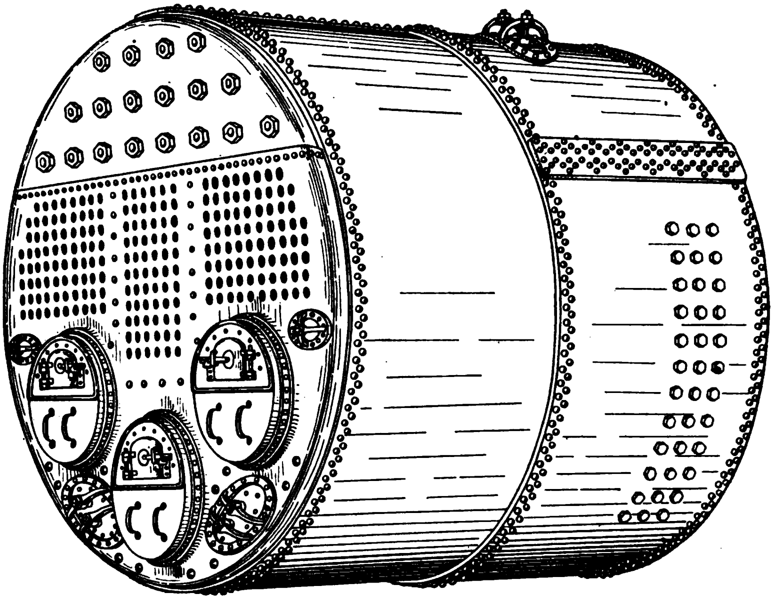


Fig. 22. Return-Tubular Boiler with Three Flues

Single-Ended Multiple-Flue Type. The boiler shown in Fig. 21 has only one furnace, but return-tubular boilers frequently have two, three, or four furnaces.

Fig. 22 shows a boiler with three furnaces. Large furnaces are more efficient than small ones because the grate area increases directly as the diameter, while the air space above the grate increases as the square of the diameter. The greater space aids combustion. The length of the grate bars is nearly constant for all sizes of flue because it is limited by the distance a fireman can throw coal. Furnace flues are usually from 36 to 54 inches in diameter. As the size of furnaces is fixed, the number depends upon the size of the boiler, for a large boiler must have a large grate area, which can be obtained only by using several furnaces. The various arrangements are shown diagrammatically in Fig. 23.

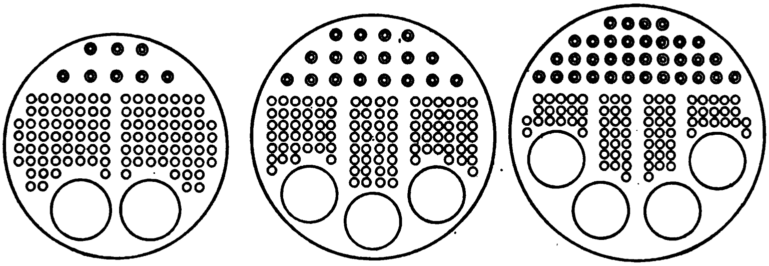


Fig. 23. Several Arrangements of Multiple-Flue Boiler Tube Sheets

Arrangement of Combustion Chambers. A single-furnace boiler has but one combustion chamber. A two-furnace boiler may have a combustion chamber for each furnace or it may have a common combustion chamber. It is better to have a common combustion chamber for the two furnaces, because alternate stoking keeps up a more nearly constant pressure of steam and there is less smoke. Three-furnace boilers usually have three combustion chambers, while four-furnace boilers have two. In case four furnaces are used with three combustion chambers, the two center furnaces lead to a common combustion chamber and each outside furnace has one.

Double-Ended Type. This form of marine return-tubular boiler is practically the same as two single-ended boilers placed back to back, but with the rear plates removed. The weight of the rear plates is saved, and there is less loss from radiation. This makes the double-ended boiler lighter and cheaper in proportion to the

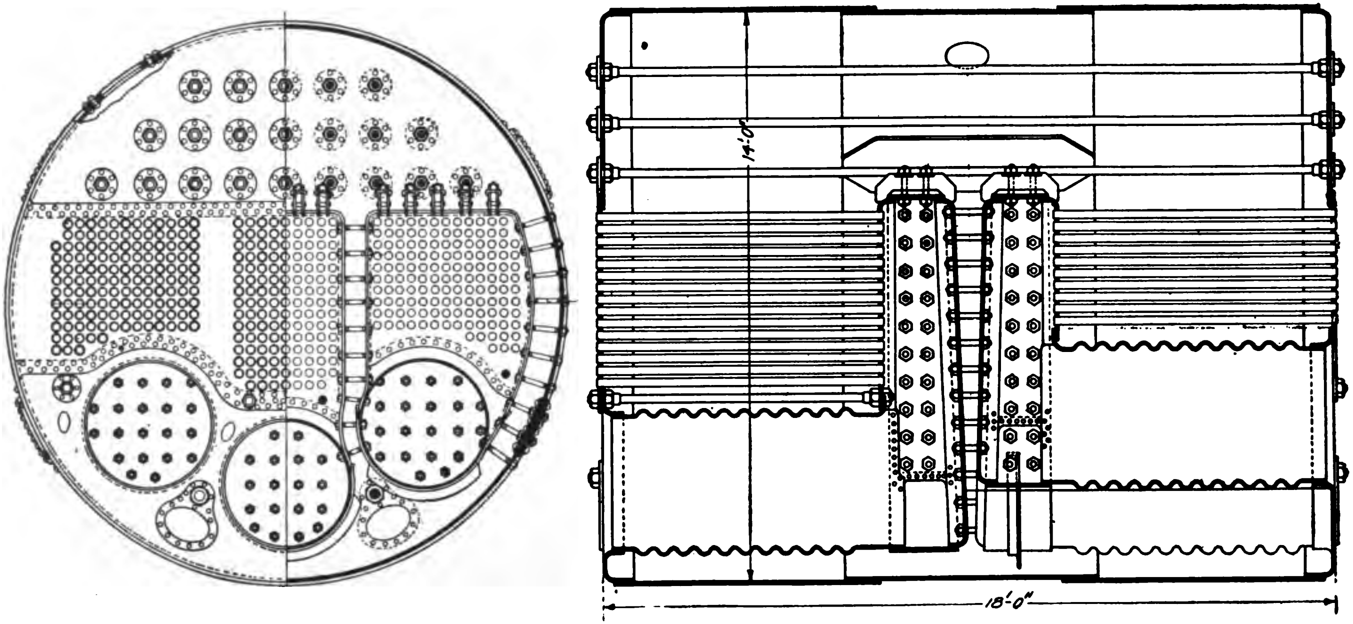


Fig. 24. Vertical and Longitudinal Sections of Three-Flue, Double-Ended, Return-Tubular Boiler

heating surface. Double-ended boilers are often made 16 feet in diameter and 18 feet long.

There are two distinct classes of double-ended return-tubular boilers—those having all the furnaces open into one combustion chamber and those having several combustion chambers. The boiler having but one combustion chamber has the disadvantage that if one fire is being cleaned the whole boiler may be cooled by the inrush of cold air. It is better to have a combustion chamber for each furnace, or at least to have a combustion chamber for the furnaces of each end. The usual method of dividing up the combustion chambers is by water spaces, as shown in Fig. 24 which shows sections of a boiler having a combustion chamber for each furnace.

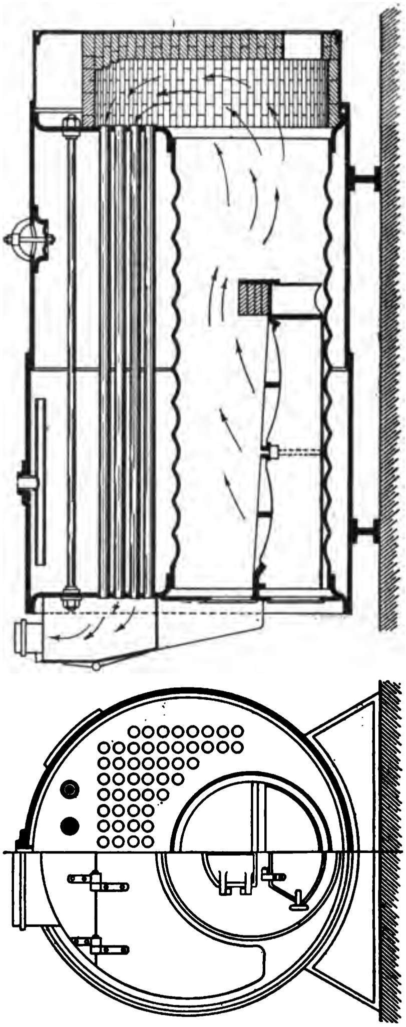


Fig. 25. Front View and Longitudinal Section of Return-Tubular Boiler for Stationary Use

Stationary Return-Tubular Type. While the return-tubular boiler is commonly used in marine work, this type, with some changes in detail, is used in stationary plants. Fig. 25 shows the construction and arrangement of parts. The flue is larger in proportion to the diameter than is the case with the marine form; the combustion chamber is partly external to the shell; that is, the rear tube sheet is also the rear end plate. This arrangement does away with the necessity of staying the flat plates of the combustion chamber.

Another form of internal-furnace return-tubular boiler is shown in Fig. 26. This boiler usually has two flues extending from the front to the back head. The grate is placed in the corrugated portion, while conical water tubes support the flue back of a bridge wall. The large furnaces and the space around the conical tubes provide a combustion chamber of ample size.

The arrows show the direction taken by the hot gases. After leaving the internal flue they enter the return tubes, which are below the furnace; before leaving the boiler, they pass underneath the shell. By this arrangement the hotter gases are near the water line and the cooler gases in contact with the cold water. Thus there is the greatest difference in temperature at all times. At each change in the direction of the hot gases, there is an opportunity for dirt and ash to fall by gravity, so that the tubes may remain clean and efficient.

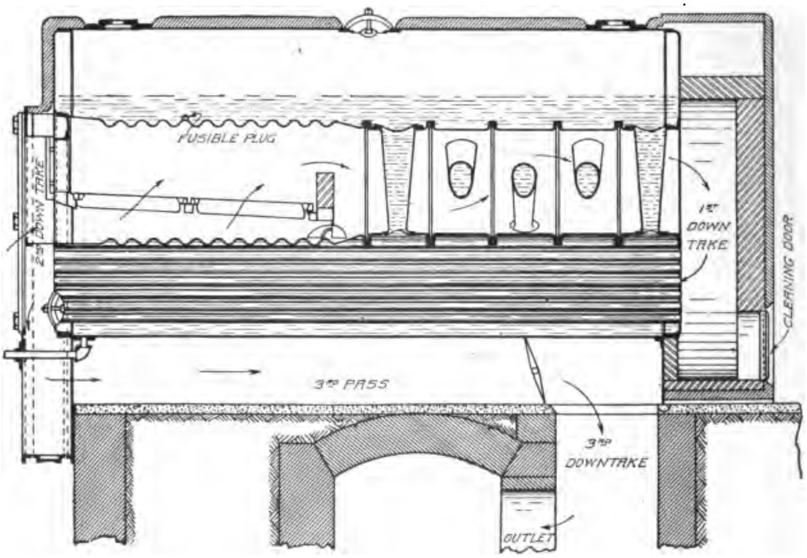


Fig. 26. Stationary Boiler of the Return-Tubular Type

With the exception of the foundation there is no brickwork. The shell is covered with a non-conducting material. This boiler, like the Galloway, has a large steam and water space, thus insuring dry steam and great reserve power.

THROUGH-TUBE BOILERS

Horizontal—Many Small Fire Tubes. Vessels of light draft require a boiler of small diameter. This is especially true of gunboats, as it is desirable to have the boilers below the water line. As there is not room for the return-tubular boiler, the through-tube, shown in Fig. 27, is sometimes used. This boiler is made up of the same parts as the return-tubular, the chief difference being that of arrangement. The rear plate of the combustion chamber forms one tube sheet and the end plate forms the other. The top of the combustion chamber is stayed to the shell by sling stays, which are bars having forked ends fastened to the shell and to the combustion chamber.

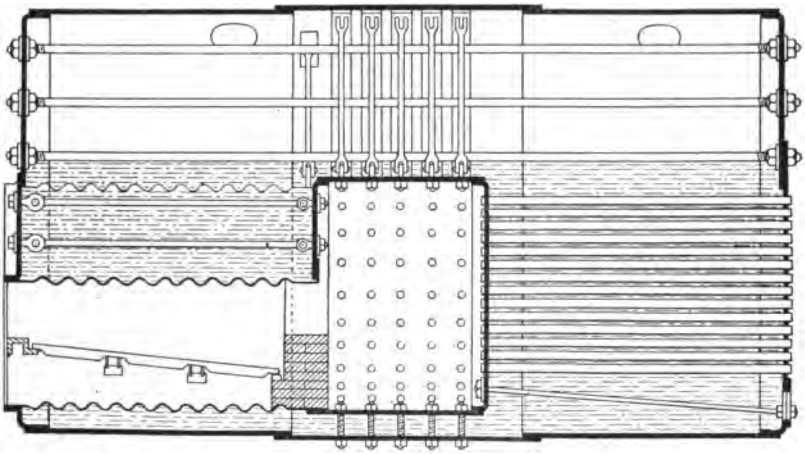


Fig. 27. Through-Tube Boiler. Longitudinal Section

The fire is in a flue, or flues, which leads to the combustion chamber. The hot gases pass from the combustion chamber through the tubes to the uptake at the back end. The chief objection to this form is its length, for the heating surface is small unless the boiler is made very long.

FIRE-BOX TYPE

LOCOMOTIVE BOILERS

Horizontal—Small Fire Tubes—Externally-Fired. Although vertical fire-tube boilers may be classed as fire-box boilers, yet the name fire-box boiler is usually applied to the locomotive type whether used with a locomotive or as a stationary boiler.

The usual form of horizontal fire-box boiler consists of a cylindrical shell, or barrel, partly filled with tubes, and a rectangular fire box. The shell is prolonged beyond the rear tube sheet to form a smoke box. The front ends of the tubes open into the fire box, while the rear ends open into the smoke box. The hot gases from the fire pass through the tubes to the smoke box, and thence to the stack or uptake. For locomotive work, there is a large number of small tubes, usually 2-inch, but for stationary work the tubes are larger and less numerous. The reason for this difference is that in the locomotive boiler a greater heating surface is necessary, and to obtain sufficient draft to burn the large amount of coal for this heating surface, the exhaust steam is turned into the smoke box. The blast of steam carries the heated gases up the stack and a fresh supply of air passes through the grate.

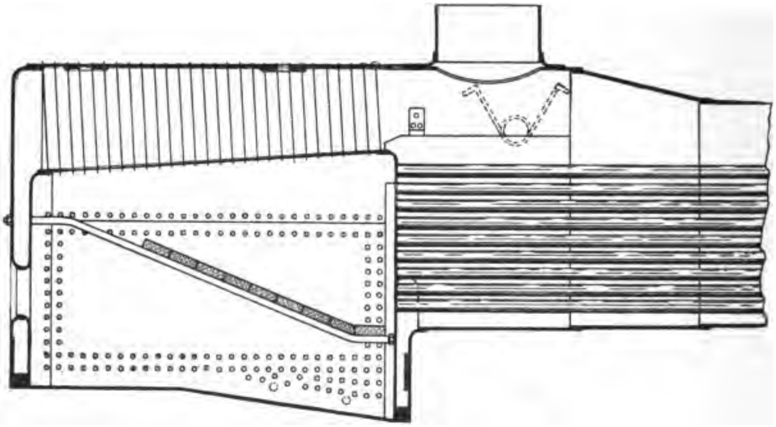


Fig. 28. Locomotive Fire-Box Boiler Showing Tube Across Fire Box to Support Tile for Furnace Arch

The cylindrical shell is joined to the fire box by riveting to a flanged ring or to a cone-shaped portion, as in the vertical boiler. The fire box has a rectangular cross section and usually a flat top. Like the vertical boiler, there is an inner and an outer shell for the furnace, the inner having the same shape as the outer, except that the top is flat. The external shell is connected to the inner by short screw stays. The space between is called the water leg. The flat top is stayed by girders or crown stays. These are sometimes attached to the shell by sling stays. The lower portions of the tube sheets are held in place by the tubes; the upper portions are stayed by diagonal stays.

The chief differences in the various forms of locomotive boilers are the shape of the fire box and the location of the grate. Locomotive boilers are either straight top or wagon top. The wagon top boiler, Fig. 28, has a cone-shaped portion by means of which the boiler is larger at the fire-box end. This construction is to give a greater steam space. The increase in size of boilers has raised the top so high above the rails that the wagon top is not now used extensively; the straight top, Fig. 29, is more common.

Belpaire Boiler. The shell and fire tubes of this type of boiler are practically the same as in any other fire-box boiler; the peculiarity lies in the fire box. The inner and outer fire-box plates are horizontal at the top, and the sides of the outer fire box are continued so that the space above the crown sheet is rectangular in section. The advantage to be gained by this construction is that the stay bolts, which hold the crown sheets and side sheets, can be placed at right angles to the sheets. This reduces any tendency on the part of the sheets to bend when under pressure.

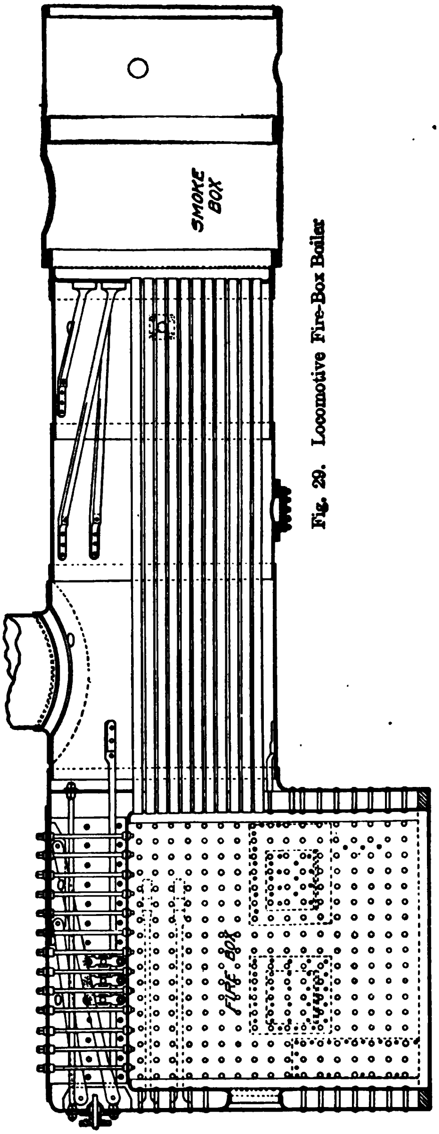


Fig. 29. Locomotive Fire-Box Boiler

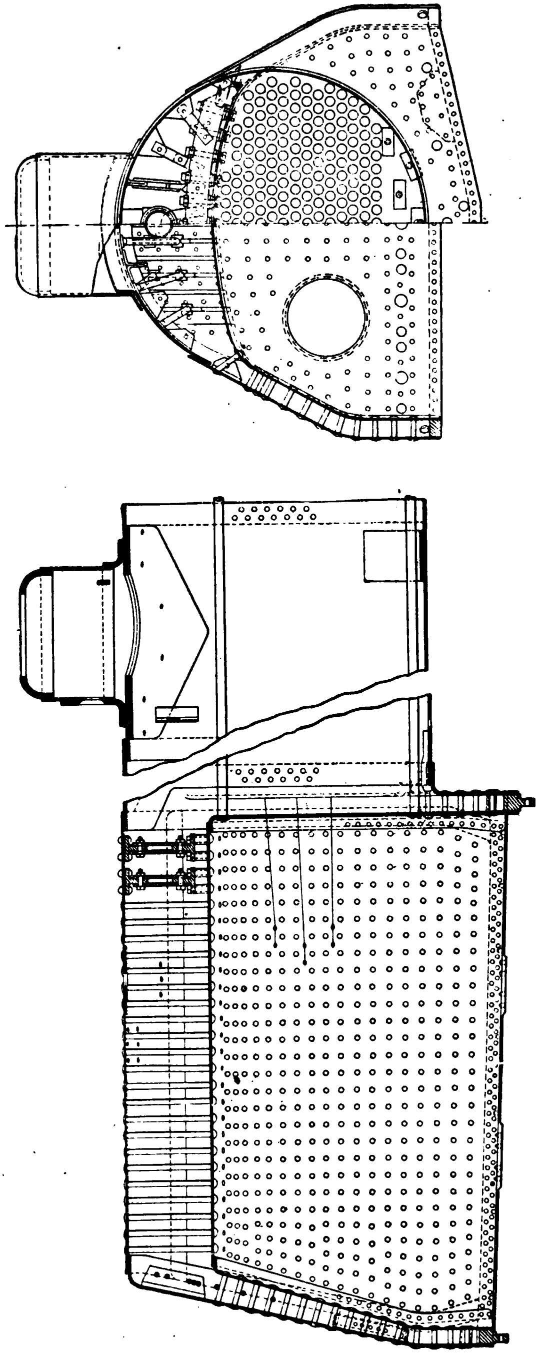


Fig. 30. Side and End Views of Wootten Locomotive Fire-Box Boiler

Wootten Boiler. In this type, also, the fire box is the chief part to be considered. The size of the locomotive fire box is limited. With older types the width was limited to less than 3 feet and the length to less than 7 feet. This was because of the frames and the distance between the axles. By placing the fire box above the axles, the width was increased by an amount equal to the thickness of the frames, or about 7 inches, and the length increased to about 11 feet. By the method of supporting the fire-box end of the boiler on trucks, the width can be still further increased.

Fire Box. A broad, shallow fire box is required if anthracite coal is used. The Wootten fire box, shown in Fig. 30, is very wide and is placed on top of the driving wheels. Formerly, a combustion chamber was placed between the end of the grate and the tubes, but, as it was found to be unnecessary, it is not now used.

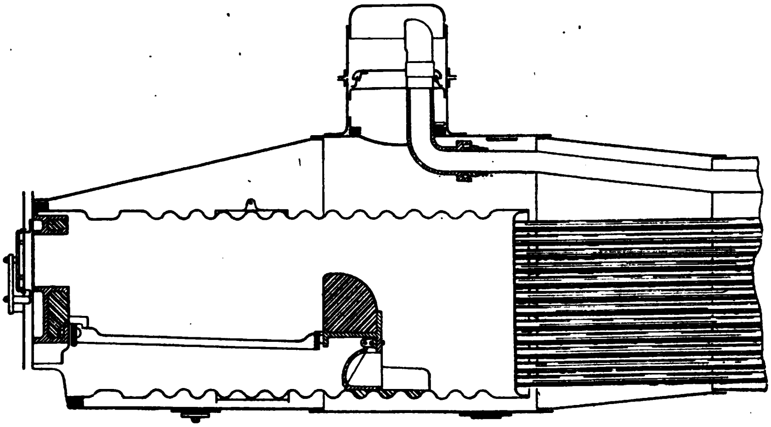


Fig. 31. Lentz Locomotive Fire-Box Boiler

Lentz Boiler. The object of the design shown in Fig. 31 is to avoid the use of stays. To do this, no flat plates are used except the tube sheets, and these are stayed by the tubes. The fire box is in the form of a corrugated flue similar to those in internally-fired return-tubular boilers. As this is circular it requires no stays. The shell is circular and shaped as shown in the illustration. This type has been much used in Europe, but only a few have been built in this country.

STATIONARY BOILERS

General Fire-Box Type. The fire-box boiler, usually called the locomotive boiler, is often used for stationary work, traction engines, and for vessels of light draft. This type of boiler, slightly modified, is sometimes used for generating the steam for heating buildings. It is economical and durable when used with natural draft. The chief differences in construction are larger tubes because of the draft, and the changes due to method of support. A common form is shown in Fig. 32. This type has been built in large sizes for high pressure, but when so made is expensive.

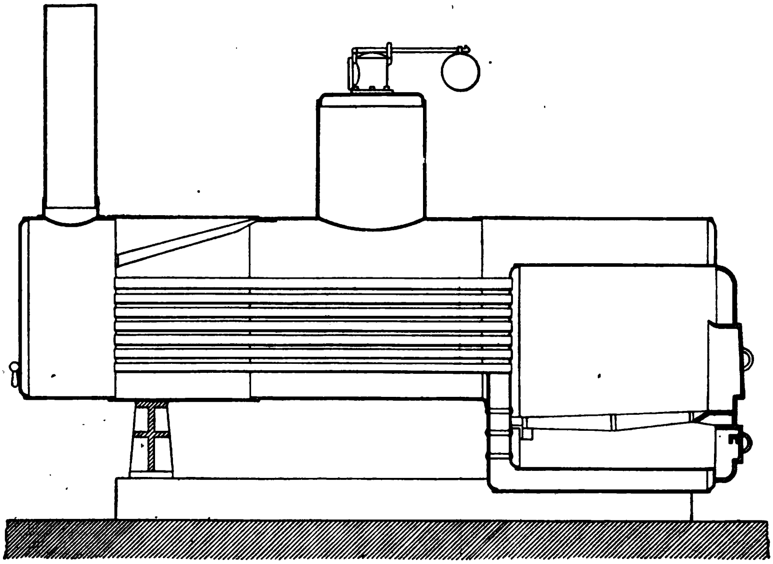


Fig. 32. Locomotive Type of Boiler for Stationary Use

PECULIAR FORMS

Return-Tubular Fire-Box Boiler. Boilers of the form shown in Fig. 33 resemble the locomotive fire-box type, but in addition have return tubes. The hot gases reach the uptake by means of these tubes instead of passing to the chimney from the smoke-box end. Thus they combine the advantages of the fire-box type and the return-tubular type without the brick setting. The water surrounds the furnace on all sides except the front. They are built in sizes from 12 to 70 horsepower. As Fig. 33 shows the construction so clearly, further description is unnecessary.

Cochrane Vertical Boiler. The Cochrane vertical boiler is somewhat like the return-tubular boiler in point of arrangement of heating surface. This boiler is shown in section in Fig. 34. The hot gases pass from the furnace to the combustion chamber, then through the tubes to the uptake. The heating surface consists of tubes and the plates of the fire box, which is surrounded by water except at the bottom. The crown of the boiler and of the fire box, being hemispherical, require no staying. The hemispherical crown also allows a large steam space. The flat plates (the tube plates) are held together by the tubes.

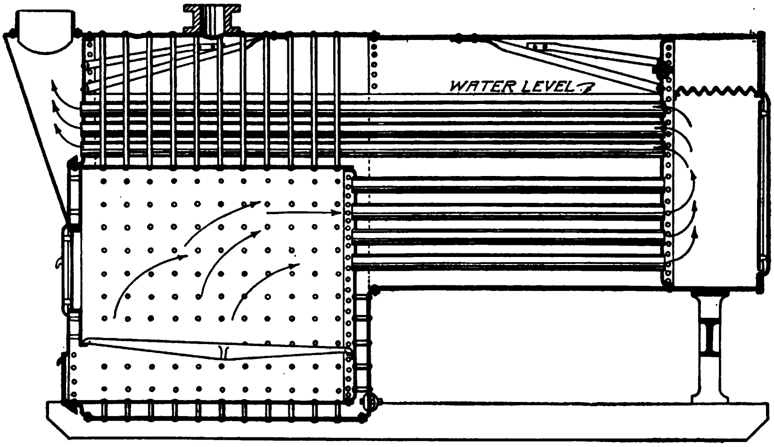


Fig. 33. Locomotive Fire-Box Return-Tubular Boiler

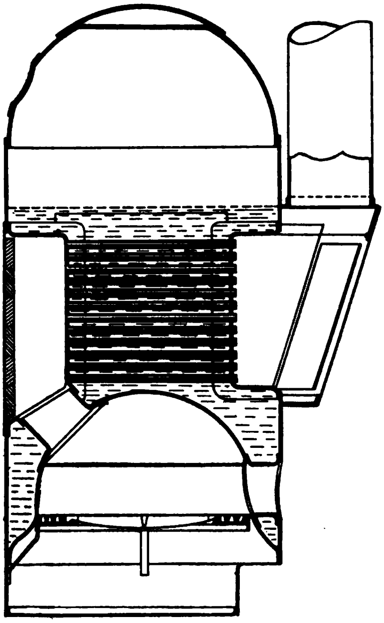


Fig. 34. Cochrane Vertical Boiler

Shapley Boiler. The Shapley boiler, shown in Fig. 35, may be called a return-flue vertical boiler. The upper portion is a reservoir for water and steam, and the lower contains the fire box. The crown sheet of the fire box is stayed to the top by through stays. The hot gases from the fire rise in the fire box and pass through short horizontal tubes to an annular space. This annular space is connected to the flue at the base by vertical tubes passing through the water space.

This boiler has a large combustion chamber; the fire box is surrounded by water, and the crown sheet and tubes are removed from the intense heat of the fire. This arrangement increases the heating surface, allows good combustion, and results in a durable boiler. The base is partly filled with water, so that any sparks carried over will be quenched.

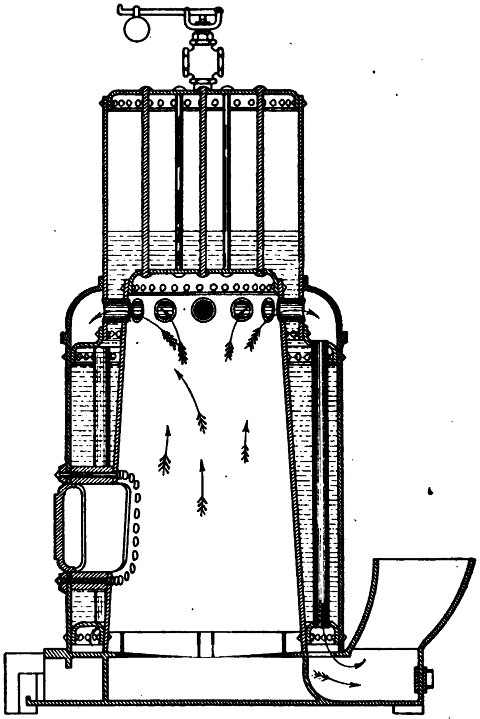


Fig. 35. Section of the Shapley Vertical Boiler

Brady Scotch Boiler. The Brady Scotch Boiler, Fig. 36, is a modification of the well-known standard marine boiler, and combines the advantages of internal firing with some virtues of its own. The lower shell contains two corrugated flues, one being shown in part section in the figure; the flues lead into a chamber at the back of the shell from which a large number of fire tubes extend over the flues, thus leading the heat to the stack at the front of the boiler. The upper drum, which is connected to the lower shell by large necks at front and rear, is kept about one-third full of water.

In the Brady boiler, positive circulation is obtained by an annular ring placed around the inside of the shell, with an opening at the bottom. (Shown by white line and arrows curving upward at bottom of Fig. 36.) As the front neck of the upper drum leads into the annular space the water is compelled to pass around the shell to the base of the boiler, where it rises around the flues and between the tubes to the rear, back of the upper drum as shown by the arrows in Fig. 36, thus establishing the proper circulation and overcoming a difficulty in Scotch marine boilers which sometimes have poor water circulation.

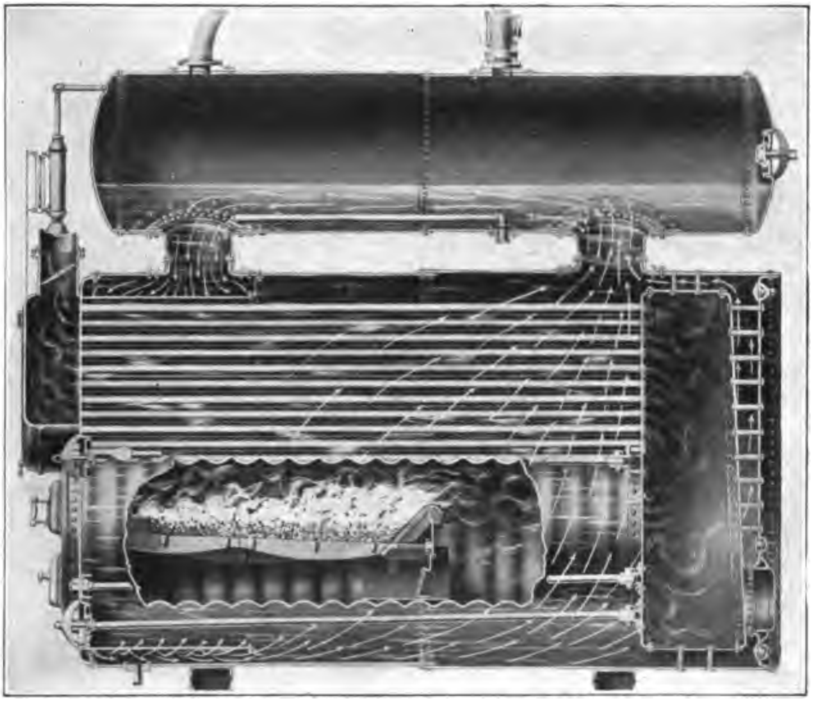


Fig. 36. Section of Brady Scotch Boiler
Courtesy of International Engineering Works, South Framingham, Massachusetts

The Brady boiler, being internally-fired, requires no brick setting and, as the hot gases in the flues and tubes are at all times surrounded by water, the losses from radiation are reduced to a minimum. Standard manholes and handholes are provided, allowing a thorough inspection and cleaning of all parts of the boiler without difficulty. The boilers are suitable for both marine and stationary work.

Directurn. The Begg's "Directurn" boiler, Fig. 37, is, in brief, a horizontal, externally-fired, return-tubular boiler in which tubes conduct hot gases through the space behind the bridge. This boiler consists of a shell partly filled with 3-inch tubes. The rear of the furnace is a throat sheet in which 4-inch tubes are expanded. The other ends are expanded into the rear end plate, which is made large enough for the purpose. The furnace is encased in steel plates lined with fire brick held in place by rods passing through the notches as shown. The manhole for entering the boiler is placed in the front head instead of in the shell, as is frequently done. A number of other makes of this type of boiler have been developed. The "Economic", Fig. 38, manufactured by the Erie City Iron Works, Erie City, Pennsylvania, is a notable example.

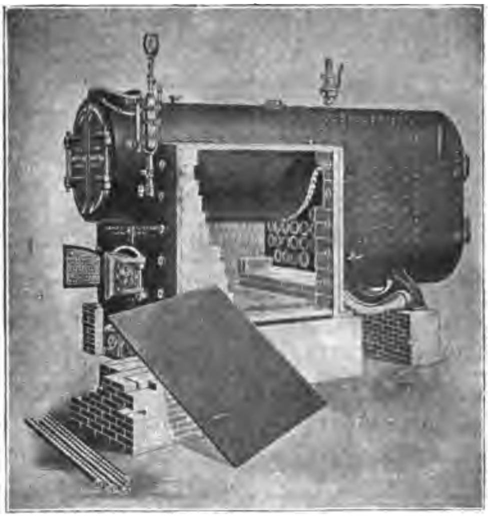


Fig. 37. "Directurn" Externally-Fired Return-Tubular Boiler
Courtesy of James Beggs and Company, New York City

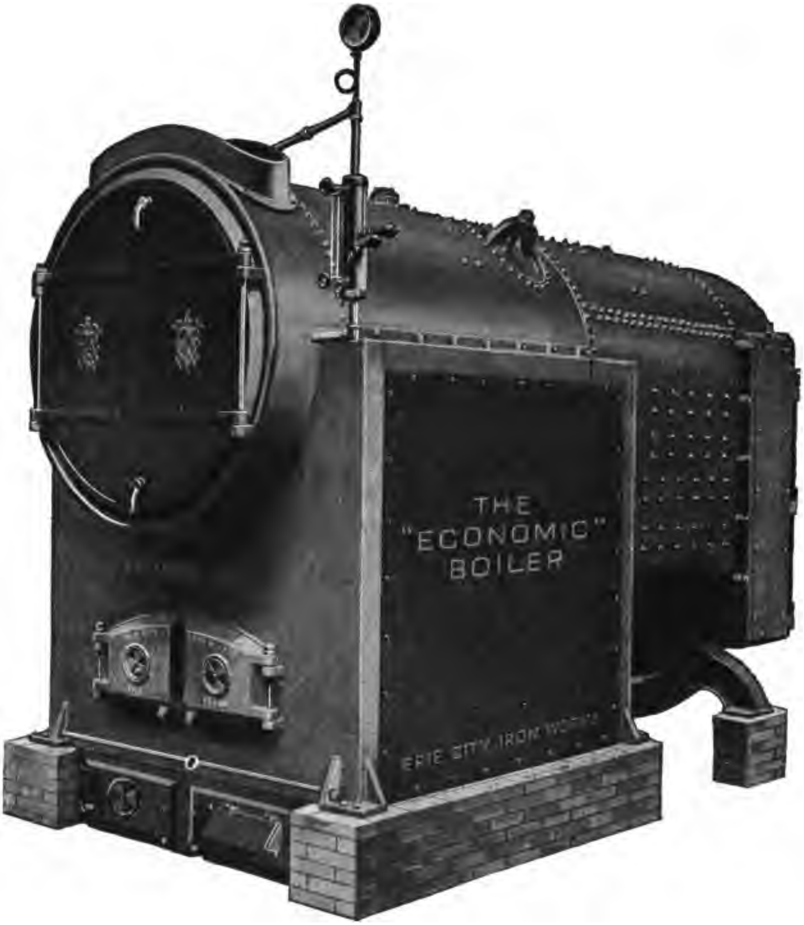


Fig. 38. "Economic" Directurn Boiler
Courtesy of Erie City Iron Works

WATER-TUBE BOILERS

General Characteristics. Water-tube boilers differ essentially from fire-tube boilers, the names indicating the chief points of difference. In the fire-tube boiler, the tubes, which are surrounded by water, conduct the hot gases to the smoke box. In the water-tube, the tubes are filled with water, and the hot gases pass over and among them on their way to the chimney.

Although flue boilers and the tubular types were introduced at an earlier period than the water-tube, yet the last-named type is not a new form of steam generator. About a century ago, John Stevens invented a water-tube boiler and fitted it to a steamboat. This boiler, Fig. 39, was a combination of small tubes connected at one end to a reservoir. Thus the "Porcupine" was one of the earliest forms. At various times since then many ideas have been worked out both for marine and stationary boilers. During the last twenty-five years, however, the water-tube boiler has been steadily growing in favor, the chief reasons being the necessity of higher steam pressures, larger capacities, greater reliability of materials, greater skill in design and workmanship, and more intelligent management.

It is not within the province of this article to discuss the relative merits of fire-tube and water-tube boilers, but a careful impartial consideration seems to show that as far as economy of running is concerned there is but little difference, providing conditions exist permitting the use of either type. The fire-tube boiler is reliable and can be handled by those possessing comparatively little knowledge of engineering; its chief defect seems to be the disastrous results following an explosion. The water-tube boiler, on the other hand, is safe, and suited to higher pressures, but in some cases requires greater manual labor in operation.

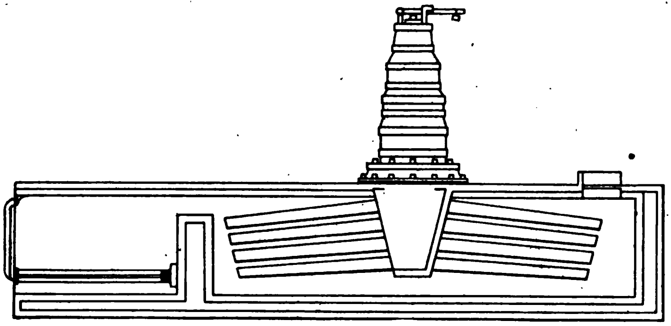


Fig 39. Diagrammatic Sketch of Stevens Boiler

Advantages. Before discussing these boilers in detail, let us consider briefly the salient points.

Safety. Probably the greatest advantage claimed for the water-tube boiler is its safety. The boiler contains much less water than does the flue or tubular boiler, and the water is divided into small masses, thus minimizing serious results in case of rupture. On account of the shape and arrangement of parts, the circulation is usually good, and no part exposed to the fire can be uncovered while there is a reasonable quantity of water in the boiler.

Rapidity in Raising Steam. The many small streams into which the water is divided as it passes through the furnace greatly facilitate the absorption of heat. Because of the small streams and the rapid circulation, the water is converted into steam in a relatively short time. Several hours, usually 5 to 7, are required to raise steam to working pressure in a tubular boiler, while in many water-tube boilers steam can be raised to over 200 pounds pressure in less than half an hour.

Durability. Most water-tube boilers are so designed that no seams are exposed to the fire or hot gases. Seams are the weakest part of a boiler and, as strains due to unequal expansion concentrate at such points, leaks, or even ruptures, are liable to occur if seams are exposed to the fire. In the water-tube boiler, the joints between tubes and tube sheets are not in the direct path of the hot gases.

Loss of Heat. The loss of heat will evidently be reduced to a minimum if the heating surface is clean and thin. The small diameter of the water tubes (2 to 4 inches) allows the use of thin metal which does not hinder the transmission of heat. The rapid circulation in the water-tube boiler prevents the accumulation of sediment, which is a poor conductor of heat. Still further, dust and dirt do not readily collect on the convex surface of water tubes, but the inside of fire tubes soon becomes choked with soot unless cleaned frequently, Fig. 40. It will be noted that the fire-tube type offers no choice as to the manner the gases are presented to the heating surface; they must pass *through* the tube longitudinally, while in water-tube boilers the gases may be forced to travel longitudinally with the tubes or compelled to cross them transversely.

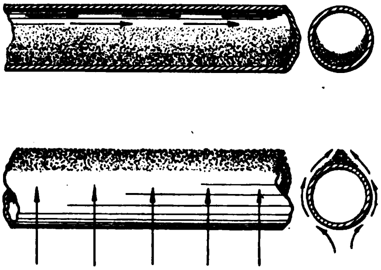


Fig. 40. Collection of Soot in Fire-Tube and Water-Tube Boilers

Less Weight. It is a well-known fact that a cylinder of large diameter must be much thicker than one of small diameter when the internal pressure is the same. The thickness of the shell of a fire-tube stationary boiler is not excessive, because of the moderate diameter; but in the return-tubular marine boiler, the shell plates for 250 pounds pressure would be about $1\frac{7}{8}$ inches thick. The difficulty of working such thick plates and their great weight render the cylindrical boiler unsuitable for high pressures. The small tubes and drums of the water-tube boiler may be made quite thin even for very high pressures. In general, it may be said that, for the same capacity and pressure, the weight of a water-tube boiler is only about two-thirds that of a fire-tube.

Classification. Many attempts have been made to classify water-tube boilers. By some writers a classification based on circulation, or on the principle of operation, is claimed to be superior to any division according to construction.

On page 4 of this article is given a classification according to features of construction. No classification is altogether satisfactory because boilers overlap into other divisions; a water-tube boiler may be sectional, of the double-tube type, have horizontal tubes, straight tubes, and free circulation. In order to have some sort of classification, and as no discussion will be entered into regarding relative merits, the classification given will be here adopted and followed as closely as conditions will permit.

Water-tube boilers are divided into two great classes—horizontal and vertical. Under these heads come sectional and non-sectional, straight-tube and curved-tube, and single-tube and double-tube. If the tubes are nearly horizontal, such as is the case of the Babcock and Wilcox, Edge Moor, Heine, and others, the boiler will be called horizontal; if the tubes are vertical, or nearly so, as in the Wickes, Stirling, etc., the boiler will be classed as vertical.

Although most boilers can be classified as already outlined, there are a few of such peculiar construction and arrangement that they must be placed by themselves under "Peculiar Forms".

As it is impossible to discuss all makes of boilers, a few representative forms will be considered as types of their respective classes. No attempt will be made to choose any make as being the best, because many conditions must be considered in selecting a boiler. The boilers described, except in a few cases, are now used extensively in either stationary or marine work.

HORIZONTAL TYPES

Babcock and Wilcox. *Water Tubes Nearly Horizontal—Steam and Water Drum Horizontal—Straight-Tube—Single-Tube—Sectional.* This boiler consists of a large number of 4-inch tubes, 18 feet long, connected to one another and to a horizontal steam and water drum. The arrangement of the parts is shown in Fig. 41, which is a side view of a much-used form of this boiler.

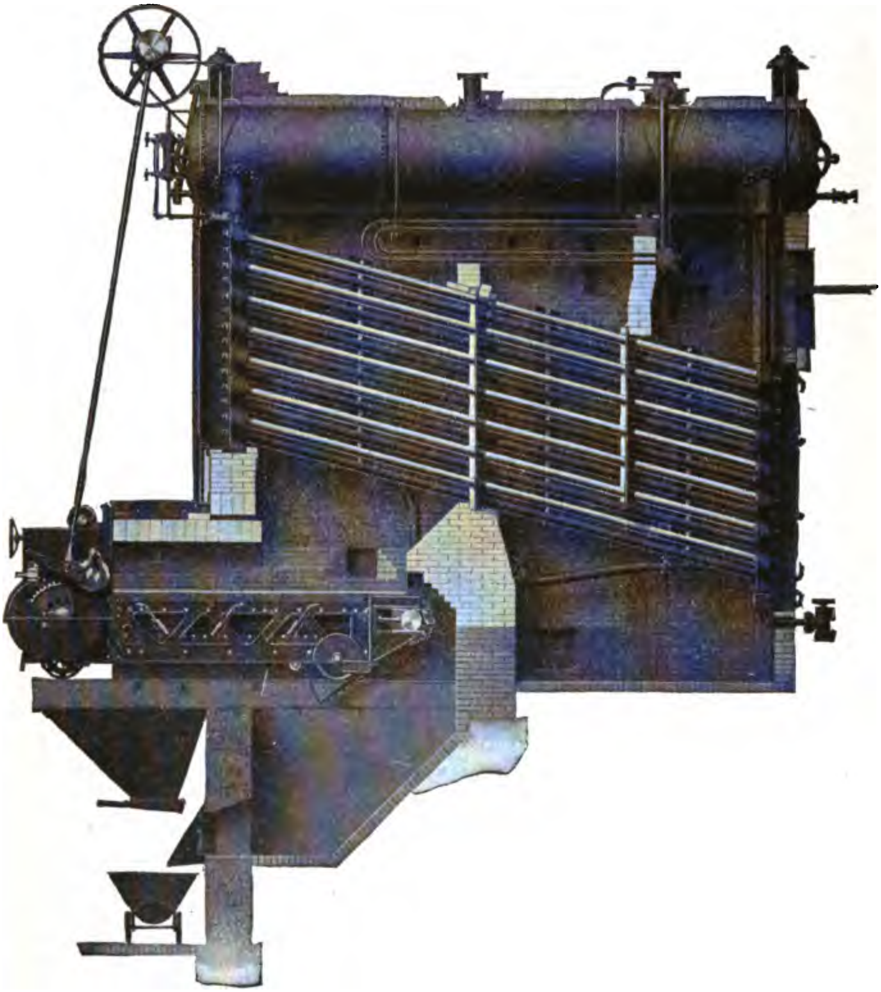


Fig. 41. Vertical-Header Longitudinal Drum B. & W. Boiler Equipped with B. & W. Superheater and Chain Grate Stoker

Courtesy of Babcock and Wilcox Company, New York City

Each tube is expanded into a header of the form shown in Fig. 42. The tubes in a vertical row enter one piece, and this vertical row is independent of the others, thus making it a sectional boiler, with a "staggered" arrangement of the tubes. In the back side of the front header, and in the front side of the rear header, holes are drilled into which the water tubes are expanded. In the front side of the header opposite each tube is a handhole fitted with a handhole plate. The details of construction are shown in Fig. 43. The tops of the headers are connected to the steam and water drum by short tubes, and the same construction is used for connecting the mud drum to the rear header.

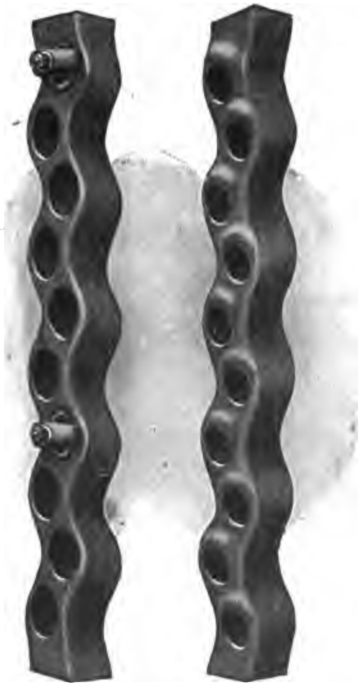


Fig. 42. Wrought-Steel Vertical Header for B. & W. Boiler

Operation. The grate is at the front end of the boiler under the higher end of the tubes. The hot gases from the fire are guided by division plates and bridges, so that after rising from the grate they pass up between the tubes; the gases then pass downward among the tubes and, after rising a second time, pass off to the chimney. In this way, the direction of the currents of hot gases is at all times almost at right angles to the tubes, thus impinging upon them instead of passing parallel to the heating surfaces, as in the case of fire tubes. As the gases impinge three times against the staggered tubes, the heating surface is very efficient.

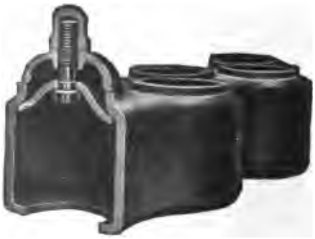


Fig. 43. Handhole Fittings for B. & W. Boiler

Circulation. The feed water enters the steam and water drum through the pipe shown in Fig. 44. It is thus heated before it mixes with the hot water in the boiler.

As the water in the tubes becomes heated, it rises to the higher end, where it is partly converted into steam; a column of water and steam rises through the header to the drum, in which the steam and water become separated. The cooler water at the rear of the steam and water drum flows down into the lower end of the tubes and, as it becomes heated, rises. Thus there is a continuous circulation.

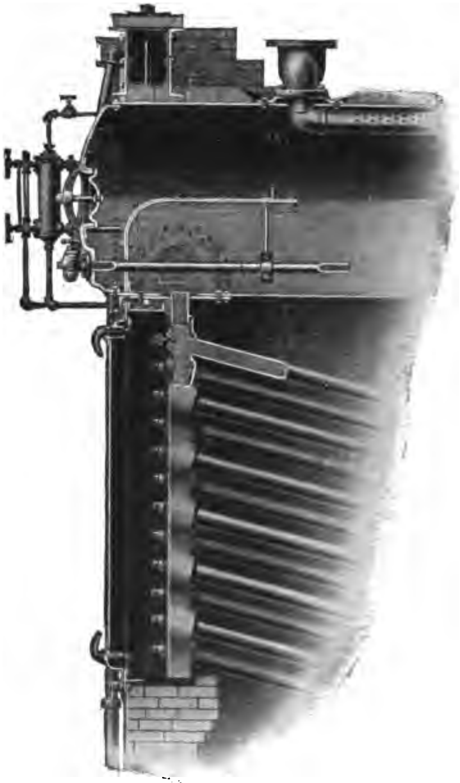


Fig. 44. Partial Vertical Section Showing Method of Introducing Feed Water in B. & W. Boiler

Steam is taken from the rear end of the steam and water drum. Much of the soft scale-forming matter and mud falls to the mud drum, from which it can be blown out.

This boiler is manufactured with both cast-iron headers and forged-steel headers; with round or elliptical outside handhole plates setting on machine surfaced seats and held by steel safety clamps on the inside; and with inside handhole cover plates of elliptical form. The forged-steel header boilers are used for the higher pressures. The marine form of this boiler has a cross drum; that is, the drum is at right angles to the tubes instead of parallel to them. It is similar in form to the cross-drum types used for stationary work. This form is used in case there is not sufficient head room.

Root. *Tubes Nearly Horizontal—Drums Horizontal—Straight-Tube—Sectional.* This brief outline indicates that the Root water-tube boiler is, in its main features, like the Babcock and Wilcox. In fact, the difference is in detail of construction only. Fig. 45 shows a longitudinal section of the boiler. Surrounding the tubes is the steam and water drum which has attached to the under side, near the front end, a cross box having openings on its face to receive the regular connecting bends from the top row of tubes.

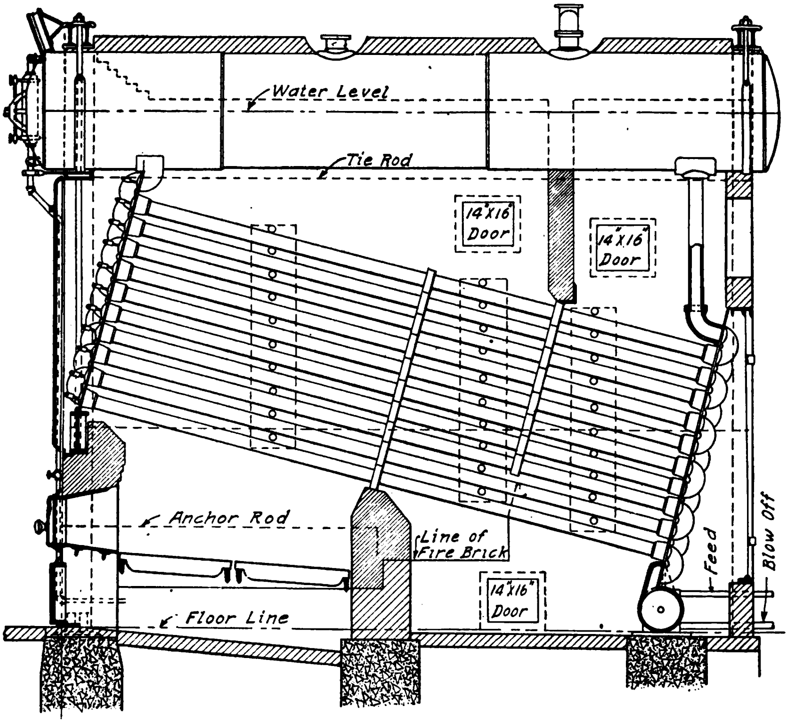


Fig. 45. Section of Root Water-Tube Boiler
Courtesy of Abendroth and Root Manufacturing Company

Construction. The Root water-tube boiler is composed of 4-inch tubes. These tubes are expanded into cast-iron headers as shown in *A*, Fig. 46. A vertical section is formed by placing one pair upon another as shown at *B*, Fig. 46. One tube of each pair is connected to one above it by a flexible bend, by means of which an uninterrupted circulation from the bottom to the top of the section is obtained. A metallic packing ring, *C*, *D*, and *E*, Fig. 46, insures a tight joint between the bend and the header.

To form the boiler several of these vertical sections are placed side by side. The theory is that these vertical rows are not to be rigidly connected because the lower tubes, being nearer the fire, expand more than those above.

Circulation. Each section is connected to the cross box of the overhead drum into which the water and steam are discharged from the tubes. At the rear of the boiler a plate is riveted to the drum and bored to receive the tubes that make the connection between the drum and rear headers. The feed water enters at the top of the mud drum, upon which the rear ends of the tubes rest (see Fig. 45), and meets the hot water coming from above. The circulating water then flows from the top of the mua drum into the lower end of the tubes. As these tubes are surrounded by hot gases, the water becomes heated and rises through the tubes to the steam and water drums. This heated water contains bubbles of steam which leave the water and collect in the steam drum. The water flows back through the steam and water drum and descends through the back header to meet the entering feed water. The water level is kept at about the middle of the steam and water drums.

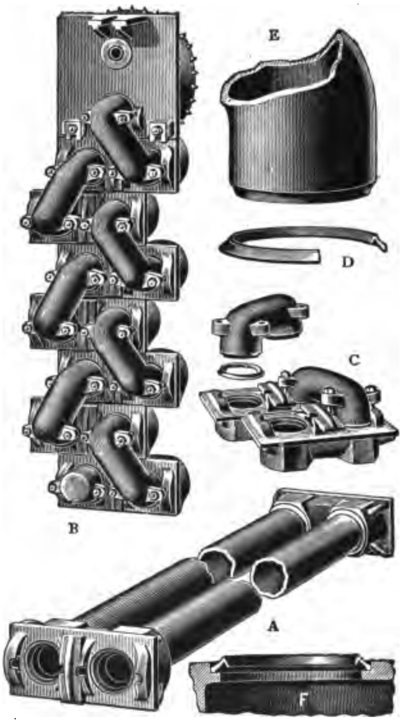


Fig. 46. Root Boiler Tube and Header Details

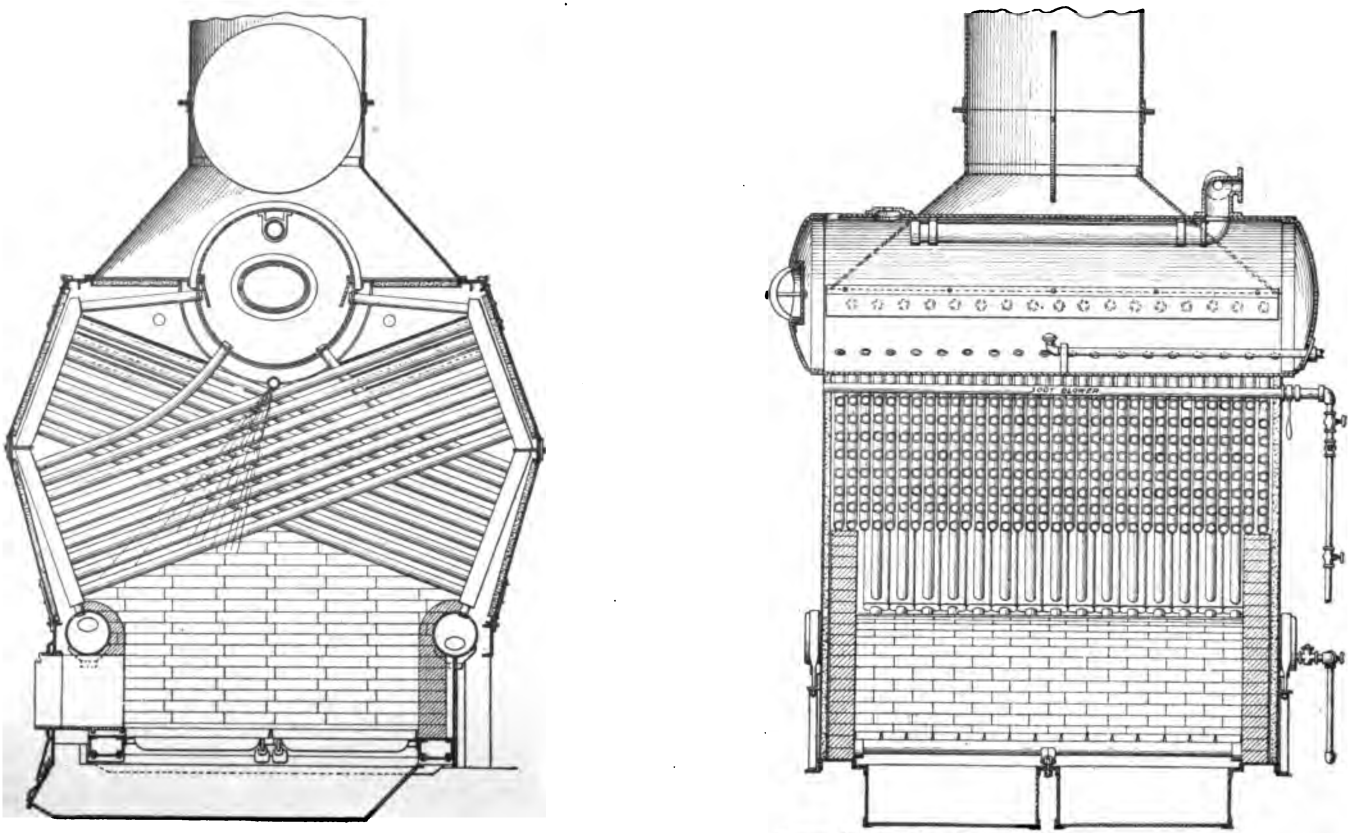


Fig. 47. Vertical Longitudinal and Cross Sections of Page-Burton Water-Tube Sectional Boiler
Courtesy of Page Boiler Company, Chicago

The hot gases from the fire pass among the tubes three times in practically the same manner as in the Babcock and Wilcox boiler.

Worthington. *Tubes Nearly Horizontal—Drums Horizontal—Straight-Tube—Sectional.* This form of boiler is much the same in principle and operation as the Babcock and Wilcox boiler, but the parts are differently proportioned and arranged, Fig. 47. The furnace extends under the entire boiler, and the tubes are set over it close together in oppositely inclined series. No flame walls or baffle plates are used.

Construction. Boilers up to 125 h. p. are usually made to fire at the end as shown in Fig. 47, in which the tubes extend across the furnace from front to back, and the steam and water drum is at right angles to the tubes as shown in the cross section. The tubes of each vertical row are expanded into straight headers which contain seven or eight tubes. Opposite each tube is a handhole. These headers are arranged close together, forming the boiler enclosure.

Circulation. The feed water enters the steam and water drum and the circulation carries it down through pipes running to the lower headers and from thence into the mud drums as shown. From the mud drum it rises through the inclined tubes over the fire into the upper headers. The water now containing bubbles of steam enters the steam and water drum by means of short tubes shown in Fig. 47.

The covering for this boiler is an iron casing, no brick being used except to enclose or line the furnace.

Edge Moor. *Tubes Nearly Horizontal—Drums Horizontal—Straight-Tube—Non-Sectional.* The Edge Moor water-tube boiler differs from those previously discussed among the water-tube class in this respect, that the tubes, instead of being expanded into sections, are expanded into box-shaped headers which are large enough to include all of the water tubes. The tubes are always 4 inches in diameter and usually 18 feet long, though they may vary from this length.

Construction. Fig. 48 illustrates the general form of construction; this same figure shows how superheating surface is added, the latter being shown by the loops located between the drums and the tubes.

Fig. 49 shows clearly how the headers are connected with the drums in such a manner as to avoid the construction of a "throat" through which the steam and water must pass after leaving the tubes in their circulation through the boilers. This is a distinctive feature of the Edge Moor boiler. Note that the drums do not project through the headers.

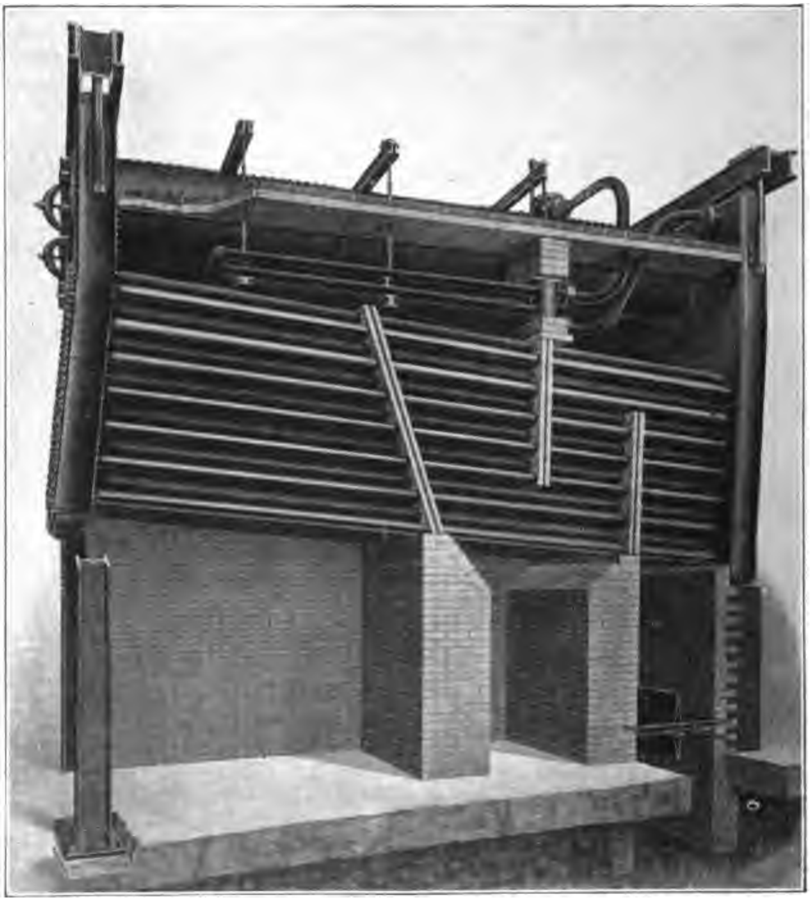


Fig. 48. Edge Moor Boiler Showing Superheaters. Boiler Construction is Standard; Setting Special
Courtesy of Edge Moor Iron Company, Edge Moor, Delaware

Fig. 50 shows the flanged handholes opposite each tube end and the elliptical cover plate, which, on account of its shape, is interchangeable and, with the aid of a gasket, carries the boiler pressure so as to hold the plate to its seat. This construction is unique on account of the flanging feature and, because the metal is retained between the handhole openings, permits desirable tube spacing opposite with the assurance that there is ample strength in the handhole sheet. The stays across the header are usually solid.

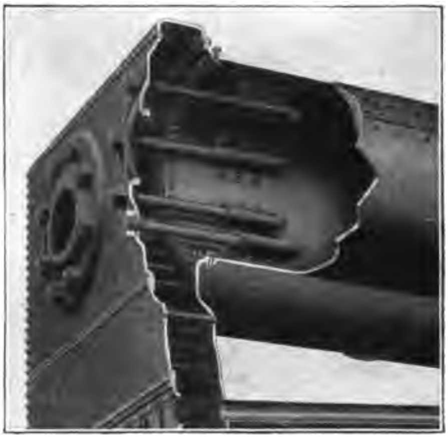


Fig. 49. Header and Drum Connections in Edge Moor Boiler

Circulation and Operation. The circulation of steam and water is identical with that previously described for the Babcock and Wilcox boiler. The aim of the construction is to provide as little internal resistance to circulation as possible by the removal of obstructions. In setting features this boiler has been installed in a great variety of ways; the normal large boiler is usually similar to that of the Babcock and Wilcox shown in Fig. 41; in special instances as shown in Fig. 48; and for the smaller sizes as shown in Fig. 52.

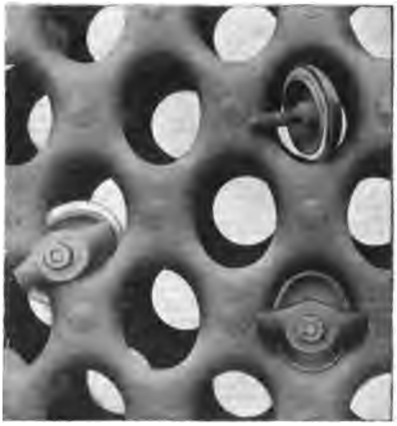


Fig. 50. Arrangement of Elliptical Flanged Handholes of Edge Moor Boiler

Heine. *Tubes Nearly Horizontal—Drums Parallel to Tubes—Straight-Tube—Non-Sectional.* The Heine water-tube boiler is not a sectional boiler. Instead of being expanded into small headers grouped to form a boiler, all the tubes, which are 3½ inches in diameter, are expanded into the inside plates of a water leg at each end.

Construction. The construction of this water leg is shown in Fig. 51. It is composed of two parallel plates flanged and riveted to a butt strap. The plates are strengthened by short hollow screw stays similar to those used in the water-leg construction of fire-box boilers. At the top, the water leg is curved and joined to the steam and water drum by riveting. Opposite each tube is a circular handhole for cleaning the tube, or replacing it if defective.

Circulation. The feed water enters at the front of the steam and water drum, Fig. 52, and flows into the mud drum, a small drum shown at the rear of the steam and water drum. From here it passes to the rear header with much less velocity. The water is warmed while passing through the pipe leading to the mud drum, and as it flows slowly through the mud drum it deposits its sediment. The accumulated sediment is blown off by means of the blow-off pipe at the rear. The water, as it becomes heated in the mud drum, rises and passes to the front of the mud drum, from which it flows in a thin sheet to the rear of the steam and water drum and to the rear water leg. From the rear water leg it enters the tubes, in which it is partly converted into steam. The mixture of steam and water enters the higher end of the drum from the water leg. A deflection plate prevents water from being carried to the perforated steam pipe shown at the highest point of the drum.

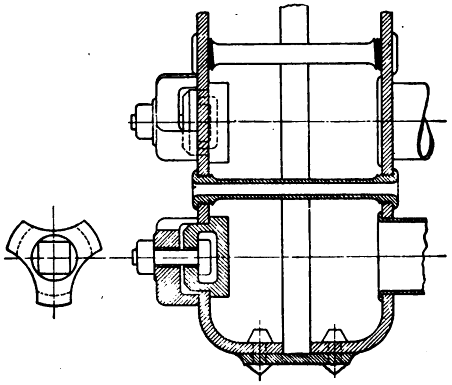


Fig. 51. Heine Boiler Water Leg

The flow of hot gases from the fire is directed by tile placed on the top and bottom rows of tubes as shown in Fig. 52. The hot gases flow nearly parallel with the tubes instead of across them as in the Babcock and Wilcox and in the Edge Moor boilers.

Mosher. *Tubes Nearly Horizontal—Drums (Cross Type) Horizontal—Bent-Tube—Non-Sectional.* The chief difference between this boiler and those already described is that it has short bent tubes, thus making a more compact boiler. This type is more often used in marine than in stationary work. The boiler consists of a large steam and water drum, Fig. 53, connected by slightly curved tubes to a smaller water drum. The steam drum is supported by two large circulating pipes, one at each end, which are connected by other pipes to the water drum. Thus the circulation is down these pipes and along the pipe at the bottom up to the water drum, and thence to the steam drum by the tubes which are in contact with the hot gases.

The feed-water heater, or economizer, shown above the main drum, consists of two small drums connected by tubes. The parallel dotted lines in the steam drum show how tubes are removed and replaced, a series of openings, which are capped with plugs as shown in Fig. 54, being provided in the upper drum for removing the tubes. All the tubes in one vertical section pass through one opening. Each plug is a conical-headed bolt, having a short piece of copper tube, a washer, and a nut. The conical head and the copper tube are inserted in the hole until the washer is in contact with the outer surface of the drum. The nut is then screwed up, thereby flaring the end of the copper tubing as shown. The

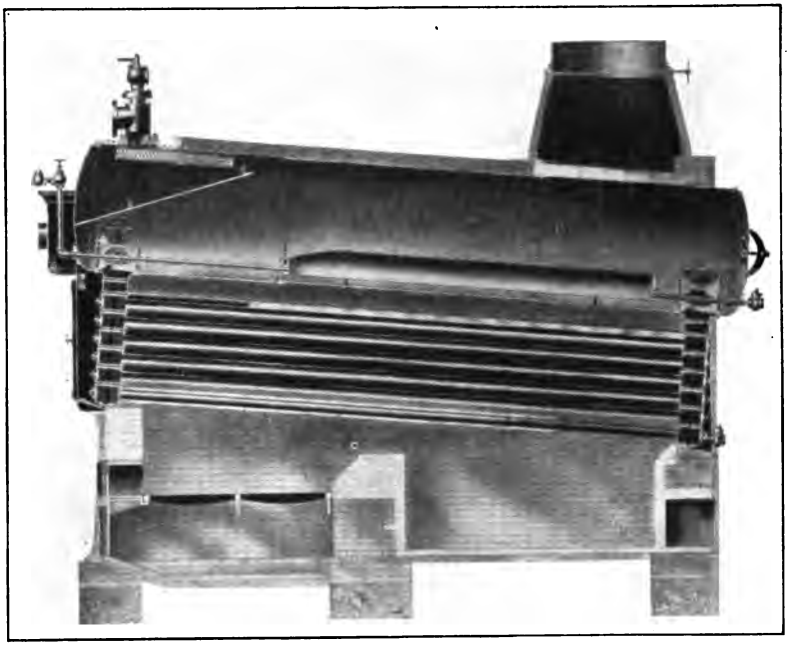


Fig. 52. Longitudinal Section of Heine Water-Tube Boiler and Setting
Courtesy of Heine Safety Boiler Company, St. Louis, Missouri

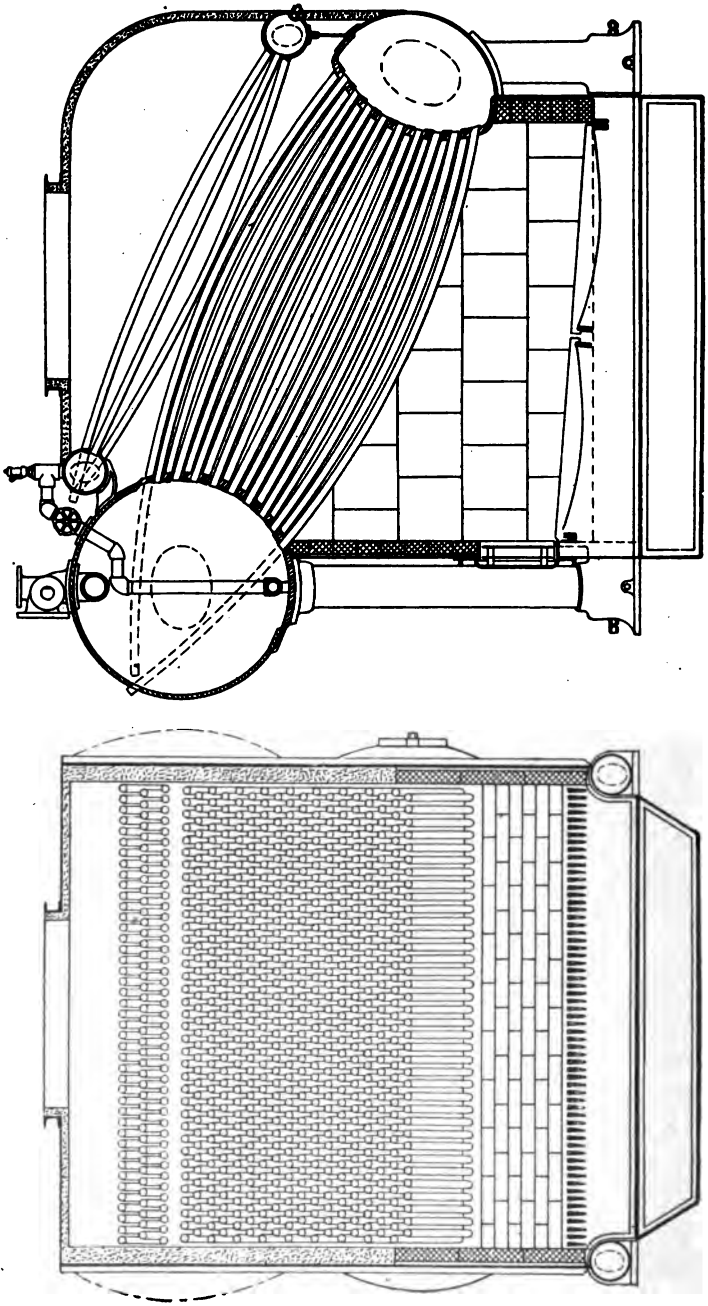


Fig. 53. Cross and Longitudinal Sections of Mosher Boiler, Showing Details of Boiler and Setting

steam pressure on the conical head increases the tightness of the joint.

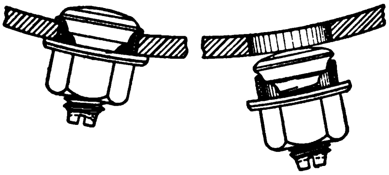


Fig. 54. Mosher Drum Plugs

Thornycroft-Marshall. *Tubes Nearly Horizontal—Drums (Cross Type) Horizontal—Bent-Tube—Non-Sectional.* The Thornycroft-Marshall non-sectional boiler consists of a large horizontal steam and water drum, a vertical water box or header, and the generating tubes. Like the Mosher, the tubes are bent slightly, but the header is quite different from that boiler.

Construction. The general features of construction are shown in Fig. 55. The steam and water drum, sometimes called the separator barrel, is simply a cylinder with dished ends. The water is carried at about one-third the height of the cylinder. The tubes, which are 3¼ inches in diameter, are connected in pairs to a junction box at one end and to a water box or header at the other end. Thus each pair forms a unit, but the two tubes of the unit are not in the same vertical plane. The upper tube enters the header as high as possible and the lower ones enter low down, thus giving considerable upward slope. From near the top of the water box, three rows of tubes lead to the separator barrel as shown in Fig. 56. The water box is simple in construction, the flat plates being stayed by short hollow screw stay bolts. The junction boxes are not restrained in any way; this construction, combined with the slight curve of the tubes, allows free expansion.

Circulation. The feed water enters the steam and water drum and then passes to the water box through the two lower sets of tubes, Fig. 55. The water enters the lower ends of the various pairs of tubes, as shown in Fig. 56, and rises in the tubes while in contact with the hot gases from the furnace. The mixture of steam and hot water then enters the header, from which it passes to the steam and water drum by means of the highest row of tubes. The difference in height of the two tubes of a unit insures good circulation. A baffle plate prevents the water from splashing to the steam pipe.

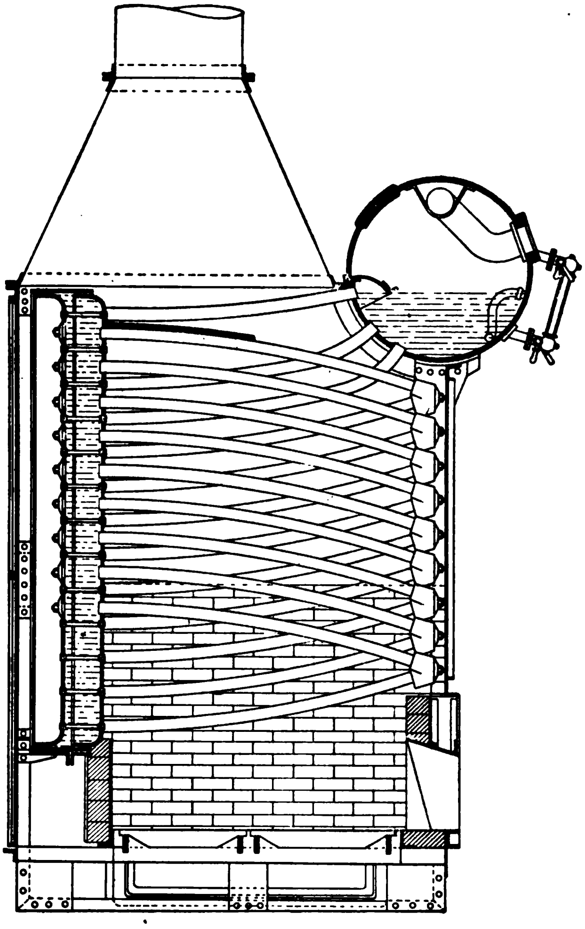


Fig. 55. Vertical Section of Thornycroft-Marshall Boiler

The hot gases pass upward among the tubes which cross so frequently that the heating surface is quite efficient.

Niclausse. *Tubes Nearly Horizontal—Drum Horizontal—Straight-Tube—Sectional.* This boiler differs essentially from those already described in that it is of the double-tube type. In general, it consists of a number of elements which form a vertical header, to which tubes are connected. The tubes are set at an angle of about 6 degrees to the horizontal. Above the elements is a transverse steam and water drum which is in communication with the headers. The general arrangement of parts is shown in Fig. 57.

Construction. The interesting feature of this type of boiler is the arrangement of the tubes and headers. To increase the circulation the principle of the "Field" tube is employed. In this construction the outer or generating tubes, $3\frac{1}{4}$ inches in diameter, are closed at one end. Each generating tube contains an inner

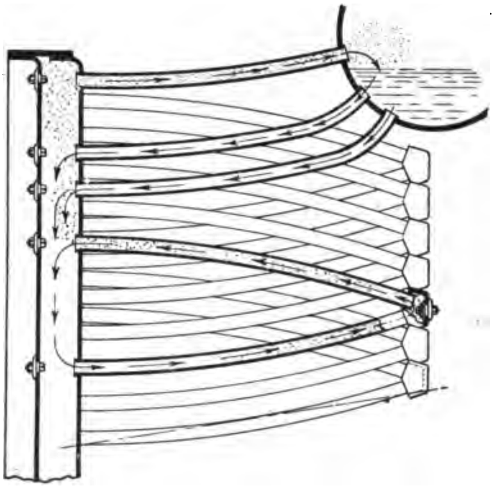


Fig. 56. Diagram Showing Circulation in Thornycroft-Marshall Boiler

circulating tube which is $1\frac{19}{32}$ inches in diameter, open at both ends. The closed ends of the generating tubes are supported by being placed in holes in a plate or rack at the rear of the boiler. The forward end of the circulating tube is attached to a cap which screws into the outer end of the generating tube. A recess in this cap provides a bearing for an arch bar which spans two tubes, keeps them in place, and is itself secured by a nut on a bolt which, in turn, is screwed into the header, Fig. 58.

The front end of the generating tubes is of peculiar shape. To allow the water to enter the circulating tubes, and to fasten the tubes to the header without expanding them, each generating tube

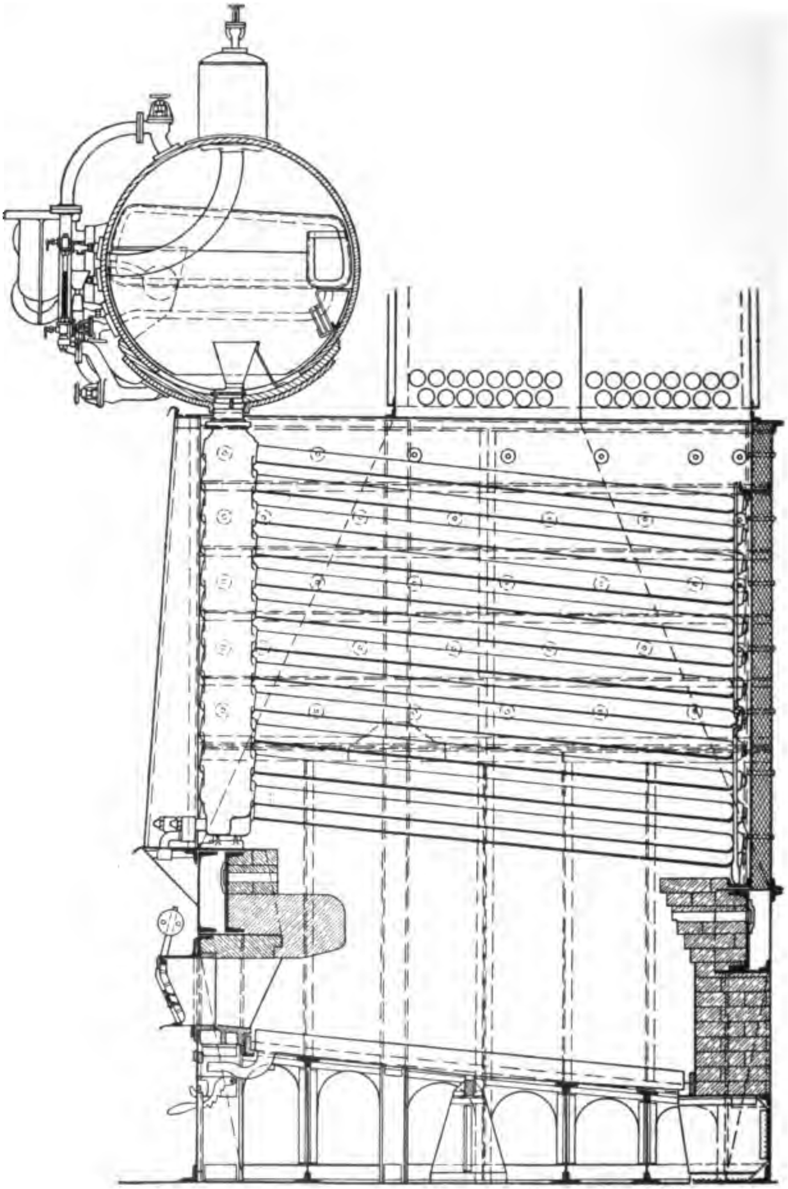


Fig. 57. Vertical Section of Niclausse Water-Tube Boiler

is provided at the open end with two cone-shaped parts; these are about 8 inches apart. The first cone fits into a taper hole flanged outward in the front face of the header, and the second cone fits a similar hole in the rear face of the header. Both the holes and tubes are ground to the same size and taper. About midway between the cones, a third expanded portion occupies the tube hole in the diaphragm or middle plate of the header, Fig. 58. The portion of the tube within the header is called the "lantern". At this point the tube is cut away so that water may freely enter the tube, the openings being above and below. In Fig. 58, the upper tube is in its normal position, but the lower tube has been turned through 90 degrees to show the construction.

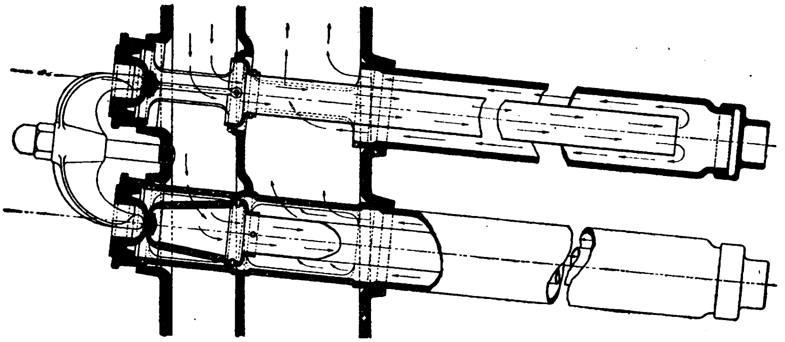


Fig. 58. Niclausse Boiler Details

To stand high steam pressures, the elements of the headers are made of wrought steel and are sinuous in shape. Fig. 59 shows the shape of the header and the positions of the tubes. Each element contains 24 tubes in two vertical rows of 12 each. In the middle of the headers, there is a diaphragm for dividing the interior. The front passage serves as a "downcomer" for the water, and the rear is the "upcomer", or riser, for the mixture of steam and water.

The lower ends of the headers are closed, and the upper ends flanged to connect with the steam and water drum, which is 42 inches in diameter.

Circulation. Fig. 58 gives an idea of the direction of circulation. Water from the drum descends in the front compartment of the header, flows into the circulating tubes, which communicate with the front compartment only, and, after flowing the length of the circulating tubes, enters the generating tubes. The water then comes back through the annular spaces in the generating tubes to the rear compartment of the header, because the generating tubes communicate with the rear compartment only, while in the annular space it is partly evaporated. The mixture of steam and water then rises to the drum.

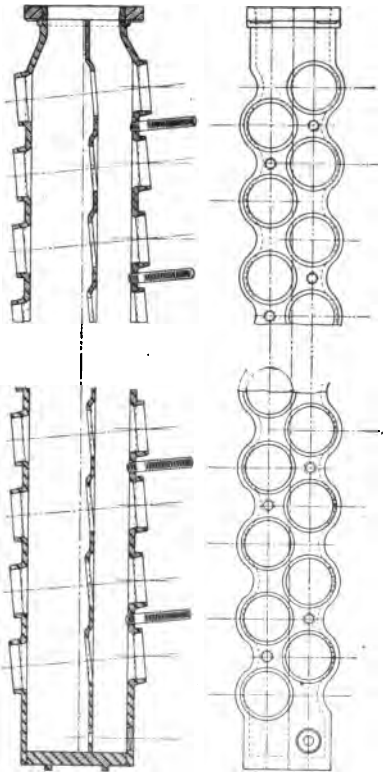


Fig. 59. Niclausse Header Details

VERTICAL TYPES

Wickes. *Water Tubes Vertical — Straight-Tube — Non-Sectional.* Let us now consider a water-tube boiler having vertical tubes. Fig. 60 shows the general arrangement of the parts of the Wickes vertical water-tube boiler. At the top is a cylindrical steam and water drum into which the upper ends of the vertical tubes are expanded. At the bottom is a cylindrical drum of the same diameter as the upper drum. The tubes are straight and plumb when in position; they are arranged in parallel rows with a clear space between rows to admit a small hoe to remove any soot that may accumulate on the tube sheet of the lower drum.

The tubes are divided into two compartments by heavy fire-brick tile. The tubes in the section adjacent to the furnace are called "risers"; those in the rear are the "downcomers", because the heated water rises to the steam drum through the front tubes, and the cooler water flows down those in the rear. The feed water is introduced into the upper drum. The direction of flow of hot gases is the same as that of the water.

The furnace is extended in front of the boiler setting and built entirely of brick. The hot gases from the fire come in contact with the tubes without passing through a combustion chamber, unless special furnace construction is adopted.

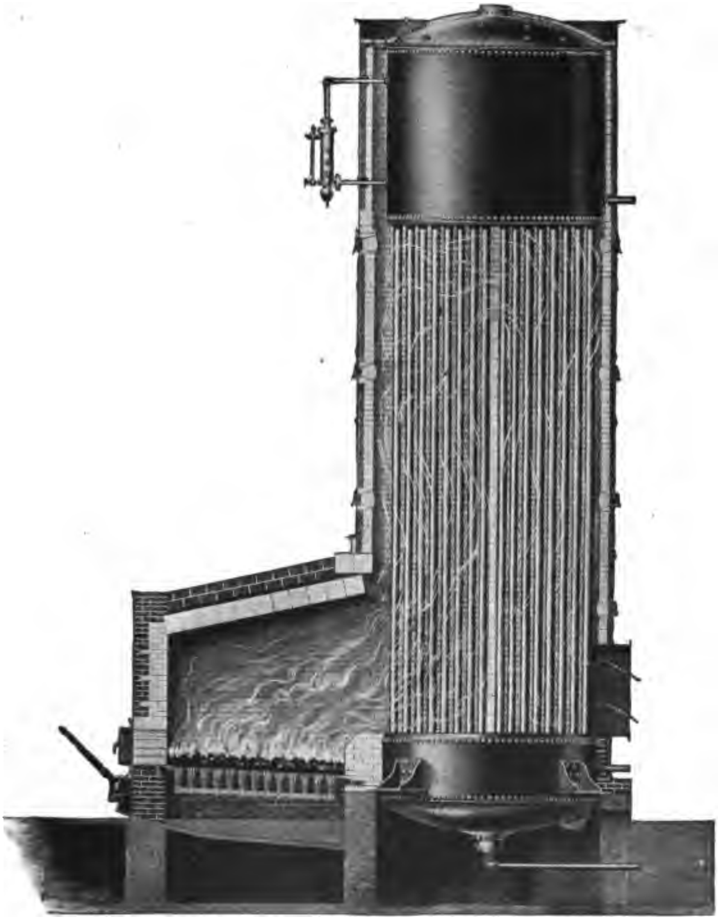


Fig. 60. Section of Wickes Vertical Water-Tube Boiler
Courtesy of Wickes Boiler Company, Saginaw, Michigan

Cahall. *Annular Steam and Water Drum—Tubes Vertical—Straight-Tube—Single-Tube—Non-Sectional.* The Cahall vertical water-tube boiler consists of an annular steam and water drum, a cylindrical lower drum, and 4-inch vertical tubes connecting these two drums. An external circulating pipe also connects the two

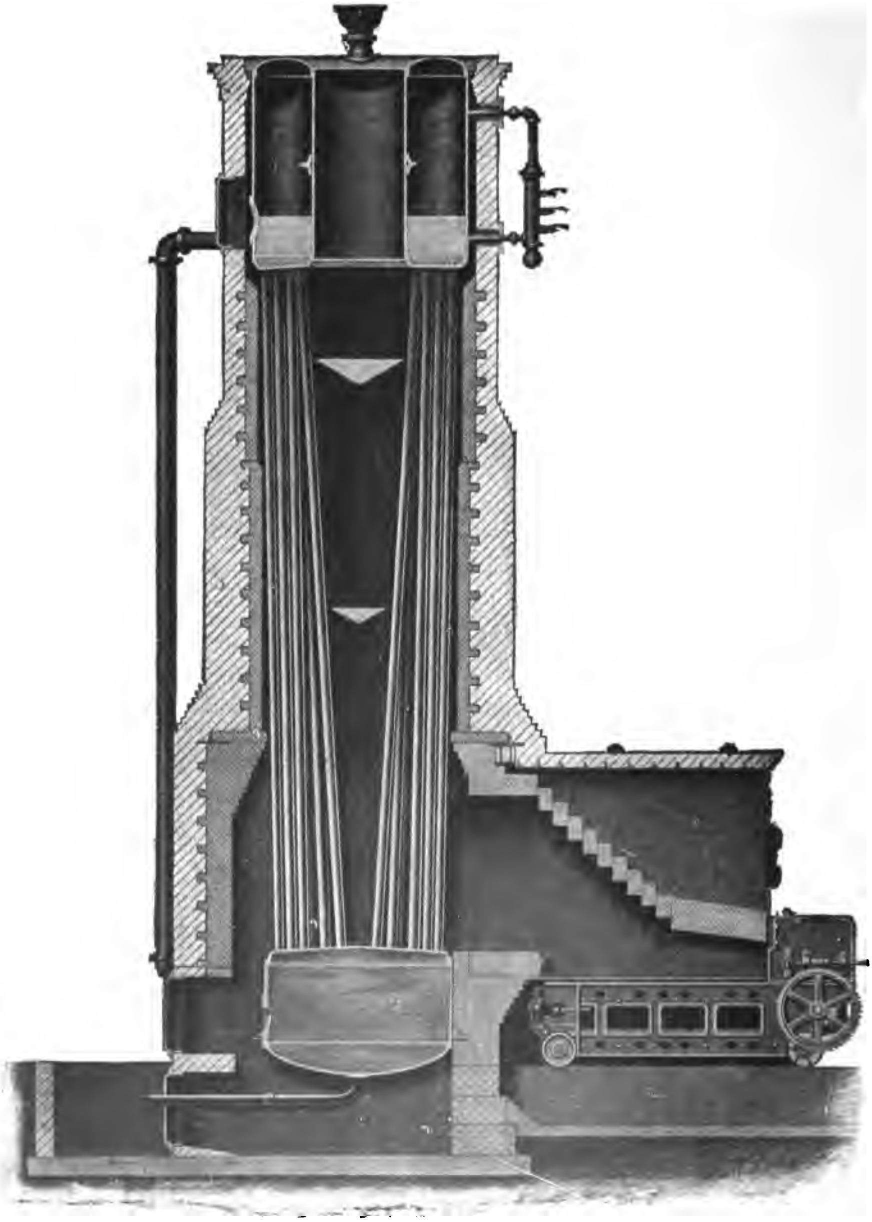


Fig. 61. Cahall Vertical Water-Tube Boiler, Showing Longitudinal Section of Setting Enclosing a Traveling Grate

drums. As this pipe is filled with comparatively cool water and the generating tubes with a mixture of hot water and steam, the circulation is up in the 4-inch tubes and down in the external pipe. The feed water enters the steam and water drum, flows down the external pipe to the lower drum, and then rises in the generating tubes to the steam and water drum.

The fire is in a brick furnace in front of the boiler, as shown in Fig. 61, the hot gases rising among the tubes. The annular form of the steam drum makes the central space conical; in this space several deflecting plates, or baffles, cause the hot gases to remain among the tubes. After heating the water in the tubes, the hot gases pass through the opening in the steam and water drum, coming in contact with the metal containing the steam. This thoroughly dries the steam and in many cases slightly superheats it.

Both the steam drum and the lower drum are equipped with swinging manheads. The steam drum also has several handholes for use in removing and replacing tubes.

Stirling. *Tubes Nearly Vertical—Drums Horizontal—Bent-Tube—Non-Sectional.* The Stirling boiler, shown in Fig. 62, consists of three cylindrical steam and water drums at the top and a mud drum at the bottom. The lower drum is connected to the upper drums by three sets of tubes which are curved slightly at the ends. The curved tubes allow for expansion and make it possible to have the tubes enter the drums radially.

The feed water enters the rear steam and water drum and, coming in contact with the hot gases just before they enter the uptake, becomes gradually warmed. This heating causes most of the sediment to fall to the mud drum, from which it may be blown out at intervals. The mud drum is protected from the intense heat of the furnace by the bridge wall.

Each set of tubes is separated from the others by partition walls or baffles of fire-brick tile, so that the gases from the furnace pass along the entire length among the first set of tubes; they are then guided downward among the second set of tubes, and, after rising again among the tubes of the third set, escape to the chimney. The fire-brick arch just above the furnace insures an even distribution of the gases and promotes combustion; the arch heats the entering air to a high temperature, thus reducing the danger of chilling the tubes by an inrush of cold air.

Steam is taken from the middle drum, which is set a little

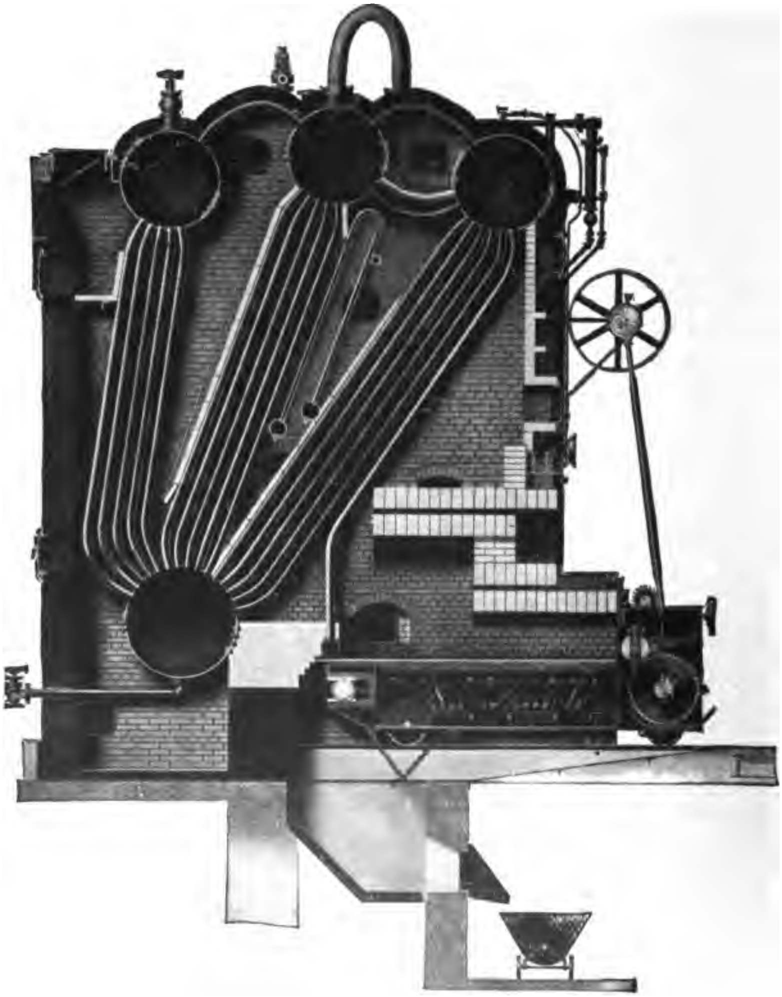


Fig. 62. Longitudinal Section of Stirling Boiler, Showing Setting and Mechanical Stoker
Courtesy of Babcock and Wilcox Company, New York City

higher than the others in order to obtain more steam space. The boiler is surrounded on the rear and two sides by the brick setting; the front is of cast iron or of pressed steel. Numerous openings in the brickwork allow entrance for cleaning.

This type of boiler is flexible and adapted to cramped places, as it can be made broad with little height or high with small floor area. All parts are either cylindrical or spherical in shape and of wrought metal. The curved tubes reduce the strains resulting from unequal expansion and contraction.

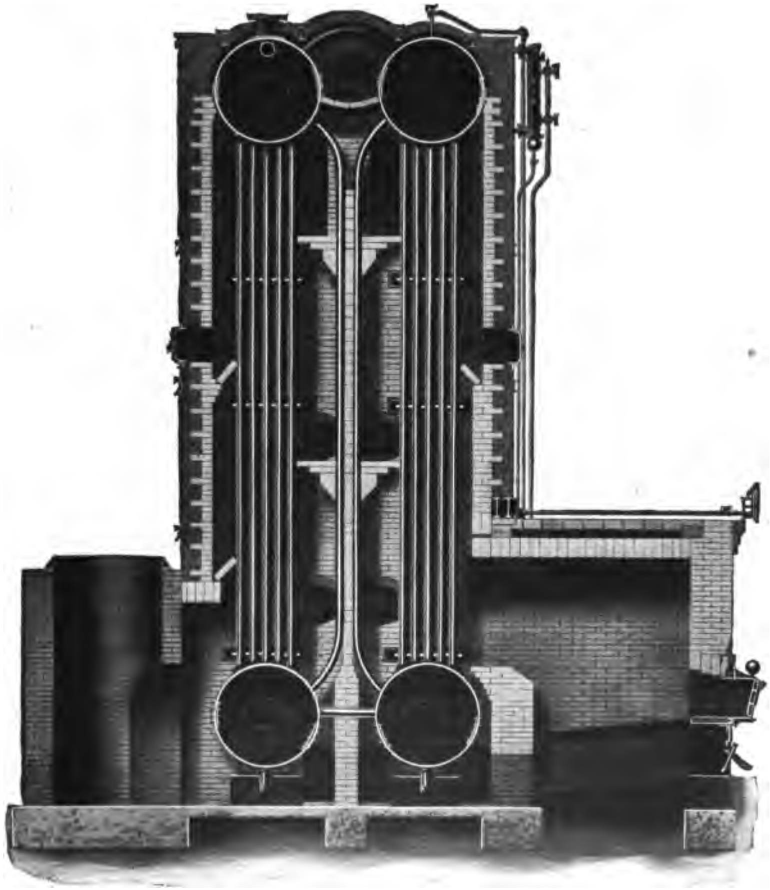


Fig. 63. Vertical Section of Rust Water-Tube Boiler
Courtesy of Babcock and Wilcox Company, New York City

Rust. The Rust water-tube boiler, manufactured by the Babcock and Wilcox Company, is intended to include the advantages of boilers made up of drums and tubes only, thus getting away from the disadvantages of header construction and many handholes, and at the same time avoiding the use of bent tubes. To accomplish this the vertical boiler illustrated in Fig. 63 is made up of straight tubes and four drums, with the exception of two rows of vertical tubes and the circulating tubes connecting the two upper drums, which are bent. The purpose of the two rows of bent tubes in the middle section is to provide a stable support for the baffle wall. When superheaters are used they are located with the elements projecting almost up to the top rear drum, close to the middle baffle wall in the space between the bent tubes and the straight tubes.

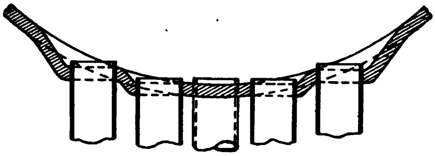


Fig. 64. Section Showing How Rust Boiler Tubes are Set into Drum

In order that the tubes may be inserted into their holes normal to the surface of the drums, the drum sheets are forged hot in a hydraulic press fitted with special dies, the effect of this forging being shown in Fig. 64.

Bigelow-Hornsby. The development of the Bigelow-Hornsby boiler is an attempt to satisfy the demand for large boiler capacity without resorting to the double- and triple-deck boiler-house design. A section consists of four tube units suspended from structural iron overhead and connected by short tubes to a central steam drum as shown in Fig. 65. As the main steam drum is the only rigid member, expansion and contraction are easily taken care of, no matter how many sections are used or how long the central drum is made. The boilers rate at 125 horsepower per section, so that a boiler of 1250 horsepower has ten sections. The water circulation is down the rear units and up the front as well as in the individual units themselves. The feed water enters the top rear unit drums and mixes with the downward circulating currents, thus providing that the coldest water shall meet the coldest gases. On account of the open structure of the boiler, it is an easy matter to inspect and clean it. As the tubes are perfectly straight, one can look through them and see if they need cleaning. The baffle-plate arrangement is shown in Fig. 65, the tile being placed at the back of each unit between the successive sections, thus making the hot gases pass through the tubes of the forward unit to the second and so on. When used, a superheater is placed below the main steam drum. This boiler is developed from the Hornsby, an English type.

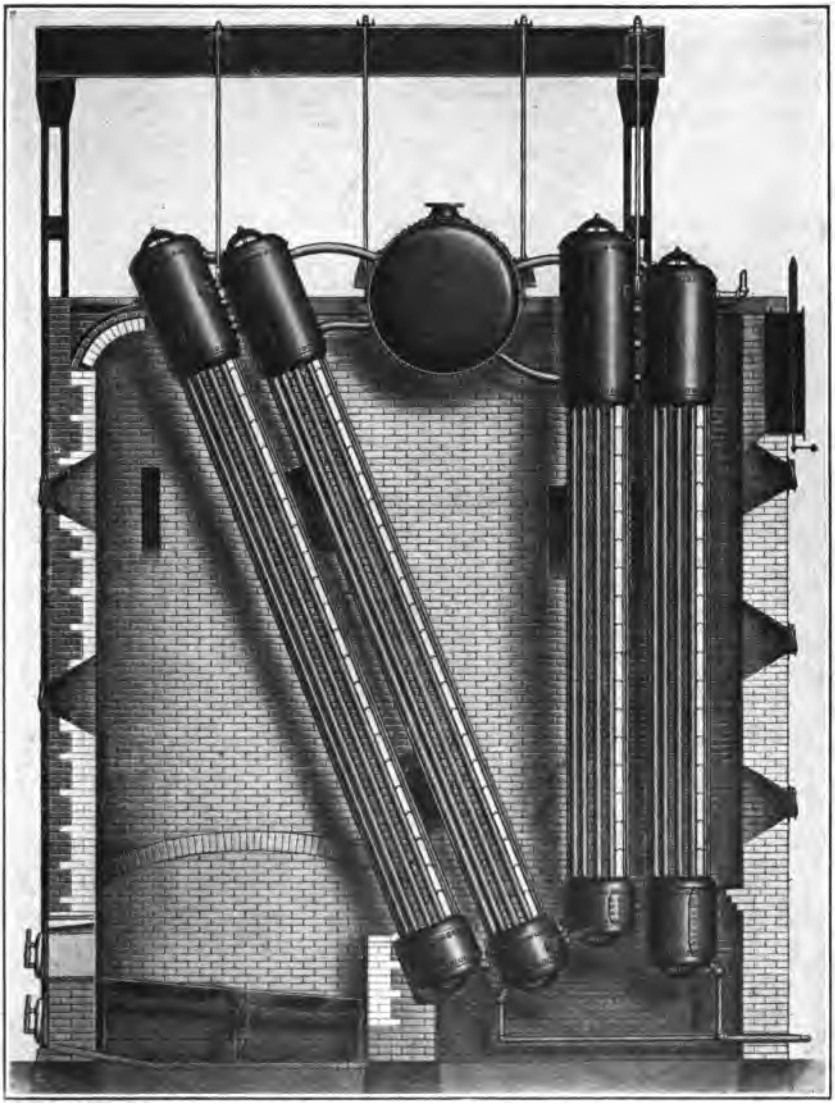


Fig. 65. Section of Hand-Fired Bigelow-Hornsby Vertical Boiler
Courtesy of The Bigelow Company, New York City

Connelly. *Tubes at Various Pitches—Drums Horizontal—Bent-Tube—Single-Tube—Non-Sectional.* The Connelly boiler, shown in Fig. 66, consists normally of two cylindrical steam and water drums and one water drum at the top, all three of which connect with a mud drum at the bottom. When the units are built especially large, this boiler may consist of as many as seven drums arranged by uniting two boilers of the four-drum type into one pressure unit, the place of articulation being the front top water drum of each, thereby permitting the rejection of one of these drums. In any of the boilers of this general design all the tubes are bent to the required shapes so as to enter the drums radially.

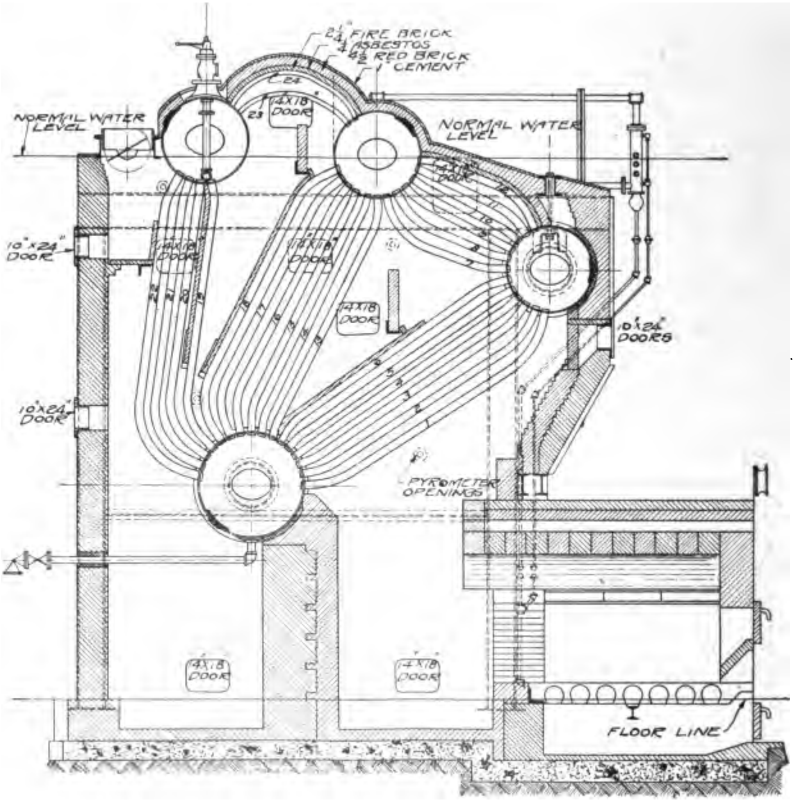


Fig. 66. Connelly Water-Tube Boiler
Courtesy of D. Connelly Boiler Company, Cleveland, Ohio

Circulation. The feed water enters the rear top drum, which is also the place from which steam is taken. Normal water circulation carries the new water from the rear top drum down to the mud drum, from which it rises to either the top front or middle drum. Steam separation occurs in the middle top drum, from which it passes by means of bent connecting tubes to the rear top drum.

The spacing is such as to permit the removal of any tube without disturbing the rest. While the boiler is baffled in several different ways, the standard form is shown in the illustration. Particular attention is called to the facilities provided for admitting a portion of the traveling hot gases to the chamber formed by the circulating tubes leading from the middle drum to the rear drum. The expectation is that heat will be delivered to the steam, causing it to be slightly superheated. It is suggested that this boiler be studied in comparison with the Stirling boiler illustrated in Fig. 62.

Erie City. *Tubes Vertical—Drums Horizontal—Bent-Tube—Non-Sectional.* The Erie City vertical water-tube boiler, illustrated in Fig. 67, consists of one upper steam and water drum communicating by means of bent tubes to a bottom mud drum. In ordinary sizes, the tubes are arranged in three banks—four rows in the front two banks and three rows in the rear bank.

Circulation. The water is fed in the center of the lower mud drum, rising in the front banks of tubes to the top drum, where entrained steam bubbles are separated. The cylindrical shell of the top drum is longer than that of the mud drum, the additional length being devoted to two internal steam compartments over which the ends of the dry pipe project so as to remove, as far as possible, the steam outlet of the boiler from the places of most violent ebullition.

Two baffles are constructed to cause the gases to follow the heating surface. The first baffle is built from the lower drum to within a few feet of the top drum, leaning upon the back row of tubes of the first bank. The second baffle extends from the upper drum to within a short distance of the lower drum. This arrangement combined with the setting walls compels the hot gases to traverse the heating surface in three passages, the outlet being at the top rear of the setting.

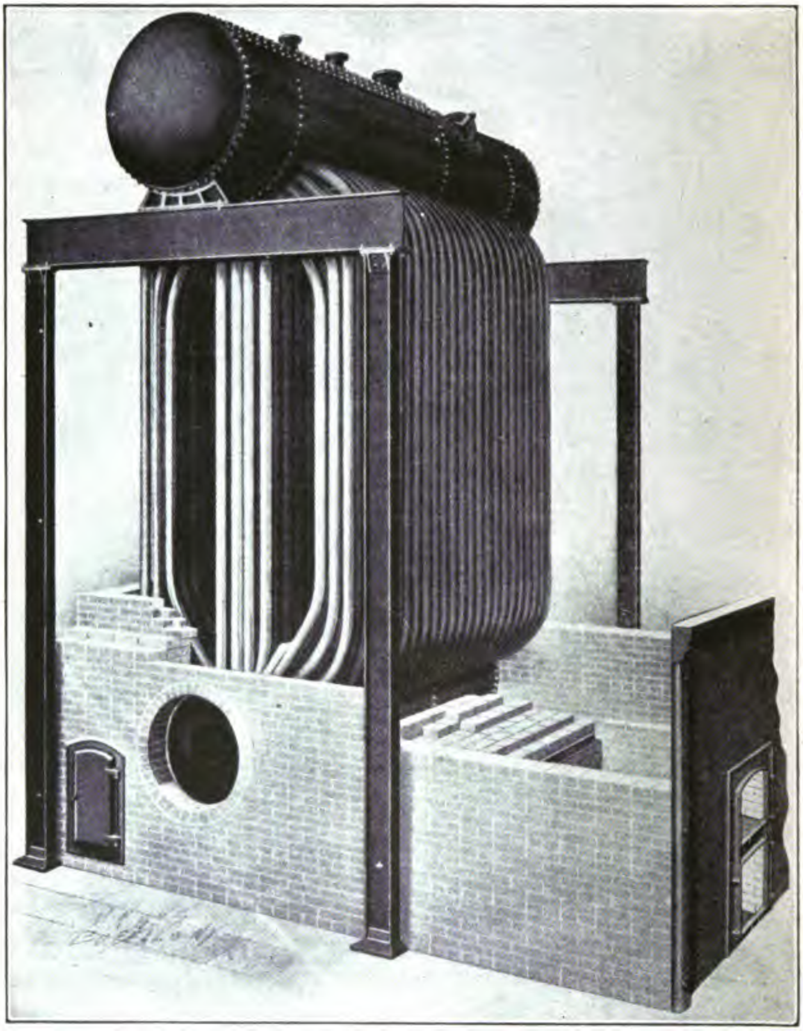


Fig. 67. Erie City Vertical Water-Tube Boiler. Brick Setting Incomplete, Baffles not Inserted
Courtesy of Erie City Iron Works, Erie, Pennsylvania

The tubes are independently removable, the spacing being so arranged. Also they are bent in such a form as to enter the drums radially.

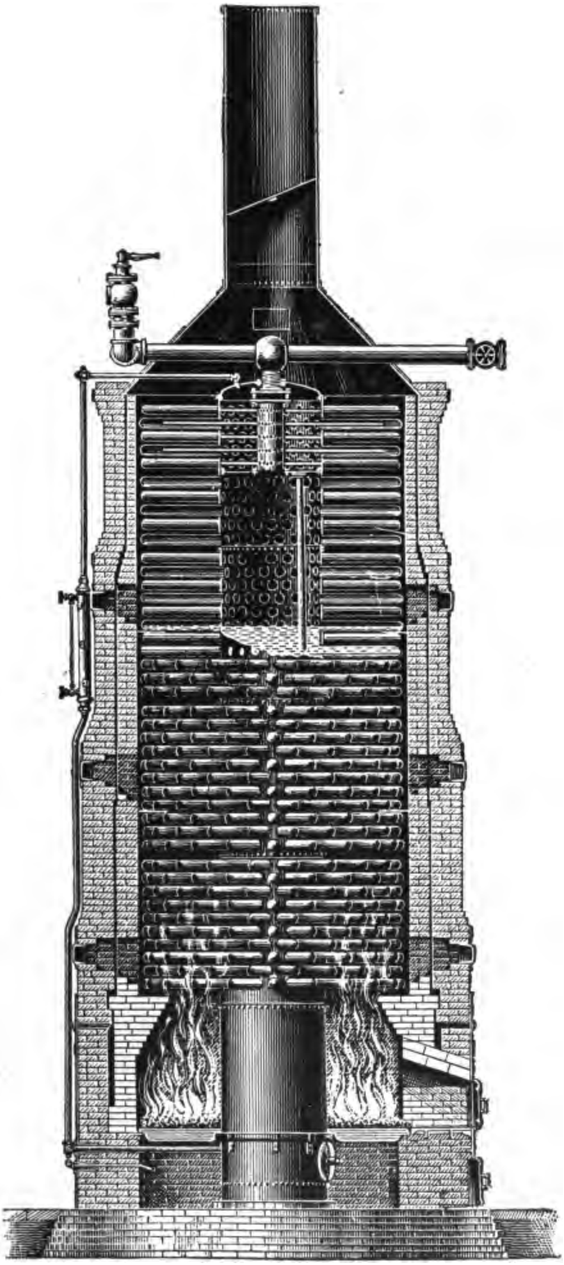


Fig. 68. Vertical Section of Hazelton Porcupine Boiler and Setting

PECULIAR FORMS

Hazelton or Porcupine. *Tubes Horizontal—Drum Vertical—Straight-Tube.* The Hazelton water-tube boiler differs in many respects from the boilers thus far described. Like most water-tube boilers it consists of a steam and water drum and water tubes, but the central standpipe is vertical and the short horizontal tubes radiate from the central drum. According to our classification it is not a vertical water-tube boiler because the tubes are horizontal; also, it is not a horizontal boiler, as in general appearance it is vertical.

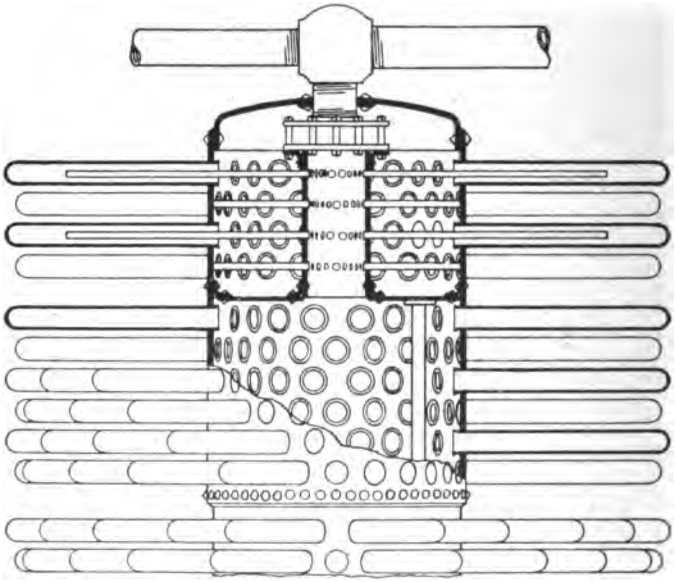


Fig. 69. Part Section of Porcupine Boiler Showing Center Tubes

The grate is circular and formed around the central drum, which rests on a circular cast-iron foundation. Above the grate, the central drum forms part of the heating surface and is the steam reservoir; below the grate it is the mud drum, which may be entered by means of a manhole just below the grate. As shown in Fig. 68, the standpipe above the fire is provided with radial tubes. The arrangement of these tubes gives the boiler the name "Porcupine".

The standpipe is about 3 feet in diameter for large boilers. The tubes are about 4 inches in diameter, and project out from the standpipe about 2½ feet, the number varying with the size of the boiler. The outer ends of the tubes are closed and hemispherical, and the inner ends expanded into the standpipe. The tubes are free to expand and contract without bringing any stress on the boiler.

Steam is taken from the top of the central drum. To get dry steam, small pipes are inserted as shown in Fig. 69. The steam passes up into the small tube at the top of the standpipe and then through the small pipes to the ends of the generating tubes. It then flows back through the generating tubes to the annular space, and thence to the steam pipe. The feed pipe enters the mud drum and extends upward nearly to the water line; it then returns nearly to the level of the grate, terminating in a spraying nozzle.

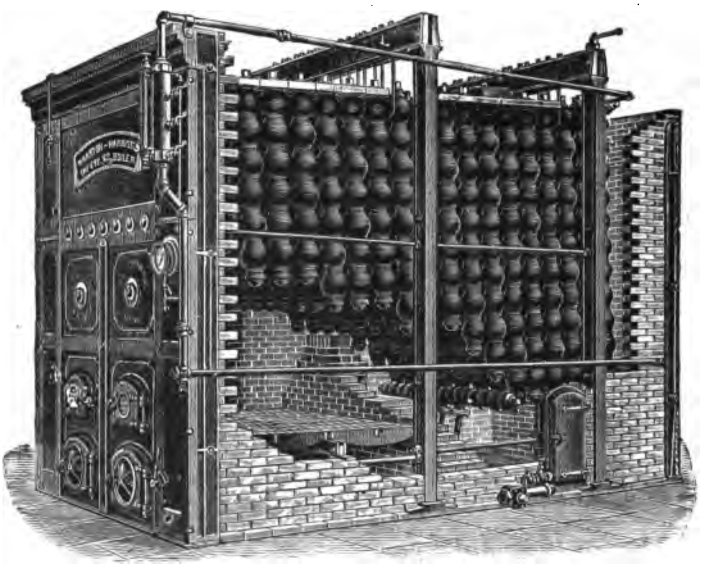


Fig. 70. Harrison Safety Boiler. A Type no Longer Manufactured but Still Used
Courtesy Harrison Safety Boiler Works, Philadelphia

This type of boiler may be enclosed in a brick setting, as shown in Fig. 68, or by a sheet-steel covering lined with fire brick.

Harrison. *Sectional—Hollow Cast-Iron Spheres Instead of Tubes.* All boilers thus far described have employed tubes as a means of dividing the water into small masses in order to make the heating surfaces more effective. In the Harrison safety boiler, Fig.

70, tubes are not used; instead, the water is contained in hollow cast-iron spheres, called units. These units, Fig. 71, are arranged in vertical rows, called slabs, which are suspended side by side, about one inch apart, from an iron framework. The brickwork setting is merely a covering to keep the hot gases in contact with the units.

The use of units in place of tubes combines great strength and a large heating surface. They are strong because small and spherical, and, on account of the division of the water into small masses, the heating surface is effective. The units are held together by long bolts which pass through the centers, as shown in Fig. 71. The machined faces make a steam-tight joint without packing. This boiler requires the same fittings as other boilers

The great advantage of this boiler is safety. From the construction, it is apparent that rupture cannot extend beyond the unit; thus disastrous explosions cannot occur. They are claimed to be durable, economical, rapid steamers, and easily handled. The capacity can be increased by merely adding more slabs.

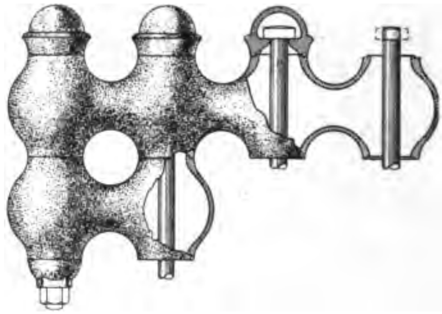


Fig. 71. Details of Harrison Boiler Units

MARINE BOILER TYPES

Elements of Design. Because boilers used in marine work must be built to meet the special conditions imposed by the construction of the ships containing them, and because boiler practice is slightly different at sea than on land, it is thought best to point out the main features of design encountered in marine boilers, grouping them together in one part of this article so as to distinguish them as a class, even though all of them must classify among the different groups according to form, as, for instance, "fire-tube", "water-tube", etc. The principles governing the construction of marine boilers cannot be different from those governing the construction of all other boilers, and whatever differences are shown come from the restrictions imposed by the spaces into which the boilers must go, and because of the attempt to reduce fire hazard.

Marine boilers usually take one of the following forms:

(1) Rectangular, or box boilers
(2) Cylindrical, or drum boilers
(3) Water-tube boilers

As was pointed out with respect to boilers used in stationary plants, the tendency is toward the greater use of water-tube boilers on account of their greater safety under high pressures, and because they are somewhat more compact for a given horsepower. It will be seen, also, that the internally-fired type of boiler, which at one time supplanted nearly every other form of marine boiler, presents the difficulty of offering very limited facilities in the matter of grate surface; and this one fact has contributed not a little to the adoption of water-tube boilers in their stead. From these remarks it must not be inferred that cylindrical boilers are not now frequently used in marine work; they are still the most common boilers on board ship, but the newer vessels, and especially the larger ones, are being equipped with water-tube boilers built particularly for marine use.

RECTANGULAR MARINE FIRE-TUBE BOILERS

Features of Construction. The rectangular boiler, Fig. 72, is made square or box-shaped; hence the sides are flat. This form was one of the earliest used; at present, however, its use is restricted to low pressure, that is, under 30 pounds per square inch. The reason why this boiler cannot be used for high pressure is because the flat plates tend to bulge outward when under high pressure. In order to prevent the plates from bulging, they must be stayed with numerous longitudinal and vertical stay rods.

Box boilers are generally made with an internal uptake, as shown in Fig. 72. This construction makes possible a larger steam space and reduces loss of heat by radiation. It is, however, expensive in first cost and repairs; also, the plates of the uptake waste rapidly, especially near the water line, because the heat is not transmitted as readily by steam as by water. In case the uptake is made separate and does not form a part of the boiler, this objection is avoided.

The tubes of the rectangular boiler are usually horizontal, or nearly so. When set inclined or with a "rake", as it is called, there is more room for manholes at the smoke-box end. The extremities of the tubes at the combustion chamber end are near the furnace, but are higher at the smoke-box end. The water level is about the same as with the horizontal tubes, the ends nearest the combustion chamber having the greater depth of water over them. The inclination is about 1 inch to the foot.

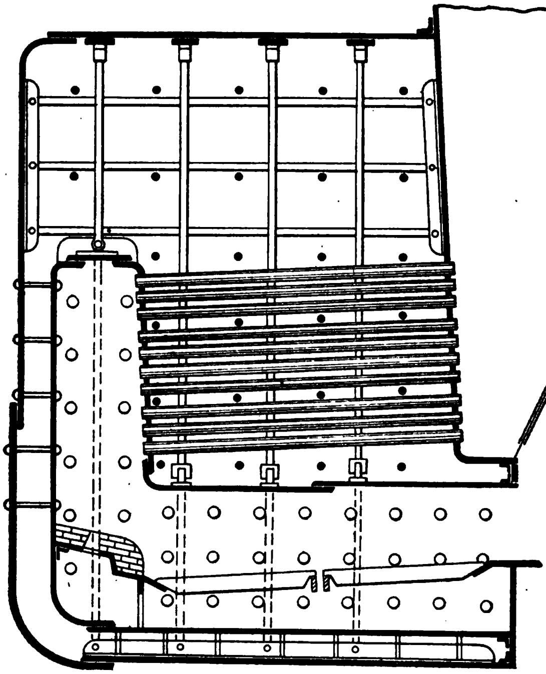


Fig. 72. Wet-Bottom Rectangular Marine Boiler

Wet- and Dry-Bottom Boilers. Rectangular boilers are made in two ways, and from the form of construction are known as "wet bottom" and "dry bottom". Wet-bottom boilers are made with the furnace wholly inside and independent of the shell, the furnaces being surrounded by water on all sides. The wet-bottom boiler is very difficult to inspect and repair.

In the dry-bottom boiler, the furnaces terminate in the boiler shell at the bottom, having a water space called the water leg between them. This water leg causes trouble by getting filled up with sediment. The furnace has water around the sides but, like the locomotive and most vertical boilers, there is no water underneath. The dry-bottom boiler is lighter, as the bottom plates are omitted, is cheaper, has greater durablity, and is easier to examine. On the other hand, it is more dangerous to the ship, as the heat is likely to cause corrosion of the frames if of iron or burn the frames if of wood.

In order to avoid the large number of stays in the steam space for pressures over 30 pounds per square inch, an oval-shaped boiler was introduced. It had a semicylindrical top and bottom and flat sides. This form was soon abandoned because it would stand only about 45 pounds pressure.

CYLINDRICAL MARINE FIRE-TUBE BOILERS

The cylindrical boiler succeeded the oval boiler. This boiler is made with the shell a complete cylinder. It is lighter, cheaper, and more easily made than the rectangular. It occupies more space and for a given heating and grate surface, has a smaller steam space. Cylindrical or Scotch boilers may be divided into three classes, as follows:

(1) Single-ended boilers
(2) Double-ended boilers
(3) Gunboat or through-tube boilers

For a detailed description of single-ended cylindrical boilers of the single-flue type see pages 23 and 24 and Fig. 21. Multiple-flue boilers are described on page 25 and shown by Figs. 22 and 23. Double-ended boilers are described on pages 25 and 27, and an excellent illustration of a multiple-flue boiler of this type is given by Fig. 24. Through-tube boilers are described on page 29 and illustrated by Fig. 27.

Locomotive Boiler. The locomotive boiler is used for launches and torpedo boats. It is a convenient form and a very light boiler for the heating surface. Forced draft is almost invariably used with it on account of the small grate area. The furnace crown, being flat, requires careful staying.

MARINE WATER-TUBE BOILERS

Comparison with Cylindrical Type. For many years the cylindrical boiler was almost the only type used in marine work, and for that reason it attained a high state of perfection. From time to time, engineers tried to introduce water-tube boilers in place of the cylindrical, but on account of poor design, faulty construction, or bad management, the experiments were not entirely successful. At the present time, however, an increase of speed is demanded and, consequently, higher pressures and lighter machinery are necessary. With this increase of pressure comes increase of weight, cost, and damage in case of explosion, if the cylindrical form of boiler is retained. Engineers have foreseen that the cylindrical boiler must give way to the steam generator which is lighter, stronger, and safer.

A water-tube boiler, if well designed and well constructed, seems to fulfill the requirements. Although the cylindrical boiler is serviceable, efficient, and can be made to stand any reasonable pressure, yet the water-tube boiler possesses many advantages over it.

The principal objections to the cylindrical boiler are the great weight, thick plates, difficulty of moving it into and out of vessels, and its small furnace space. This last disadvantage has already been discussed. Also, when the cylindrical boiler is under forced draft, the time allowed for the products of combustion to give up their heat is short.

Among the advantages of this boiler may be mentioned economy and steadiness in supplying dry steam, and in this respect it excels the water-tube boiler. It is also far better suited for salt water than is the water-tube boiler, but this is not a great advantage at the present time.

Classification. Water-tube boilers are built in a great variety of designs. They may be divided into different classes, as straight tube and curved tube; or the drowned tube, that is, those having the upper ends submerged, and those having the upper ends opening into the steam space; or those having a steam drum and those having none.

For convenience let us divide them into two classes, straight and curved tube. In the first class we may place, among others, the Almy, Belleville, Babcock & Wilcox, Heine, Yarrow, D'Allest. and Niclausse. A few of those having curved tubes are the Thornycroft, Normand, Mosher, and Ward. Some of these have been discussed in the preceding pages. Only a few of these boilers need be described here, the purpose being to show the manner in which ordinary land practice must be modified to conform with the requirements for marine use.

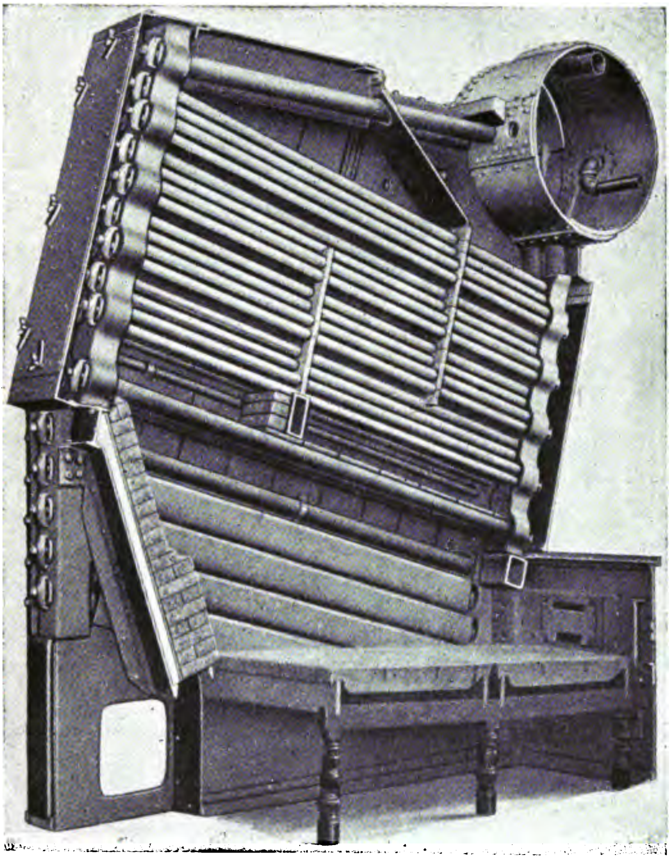


Fig. 73. Sectional Model of Babcock and Wilcox Marine Water-Tube Boiler
Courtesy of The Babcock & Wilcox Company, New York City

Babcock & Wilcox Marine Water-Tube Boiler. In Fig. 73 is shown a sectional view of a model of a marine type of the Babcock & Wilcox boiler, looking from a rear position toward the firing end. All the essential features of this boiler are clearly shown, there being set up for purposes of the illustration two complete sections united with the end of a steam and water drum.

Attention is called particularly to the forged-steel rectangular-shaped boxes, inclined at the same angle as the tubes, lying alongside the grate surface and communicating with vertical forged-steel headers. With the exception of the bottom row of tubes and the circulating tubes above, it is customary to employ small diameter tubes expanded into forged-steel serpentine headers in groups of four. Each handhole communicates with a group of four tubes, the idea being to avoid the use of a multiplicity of handhole caps.

It will be noted that the transverse method of baffling is employed, but that the low end of the boiler is located in front. The bottom row of tubes supports tube tile projecting upward from the inner end of which is the first cross-flame plate encountered by the gases. The gas outlet is at the top front immediately behind the cross-drum. The boiler is enclosed within a steel casing lined with fire brick, and the whole constitutes a very compact economical boiler. To prevent harmful galvanic action and, consequently, internal corrosion, it is customary to install zinc plates with positive metallic contact between these plates and the iron attached to the steam baffle plate within the boiler drum. The plan is to employ an electropositive metal which will receive corrosion attack in preference to the metal of the boiler when galvanic action takes place. Even though such action ceases after a few hours of operation, it is important to employ zinc as a protection against corrosion owing to the presence of air in the feed water.

Standard Water-Tube Boiler, U. S. Wooden Steamships. In order to expedite the building of boilers for the United States emergency fleet, the U. S. Shipping Board Emergency Fleet Corporation, having charge of the building of the ships for the Shipping Board, designed the boiler illustrated by Fig. 74. This is like the Babcock & Wilcox marine previously dealt with in being a straight-tube cross-drum boiler but differs from it in several important particulars. The scheme of design is such as to permit the construction of the boiler in any well equipped shop, making it possible for a relatively large number of boiler manufacturers to engage in production rather than confining the output to the capacities of a few boiler shops only. It was the preservation of this production feature which led to the selection of a "box header"

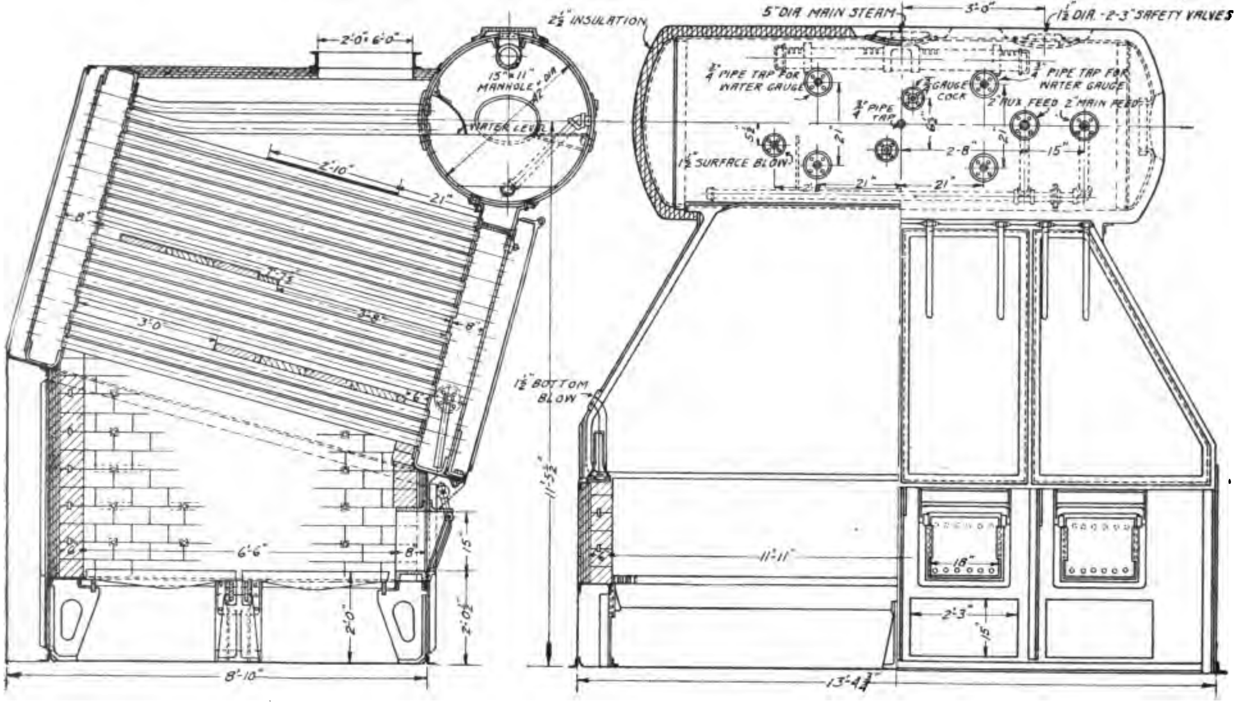


Fig. 74. Longitudinal and Cross Sections of Standard Water-Tube Boiler for Wooden Emergency Fleet

construction instead of the sectional type, which in turn influenced the design by the selection of tube sizes and spacing to fit.

The system of baffling is longitudinal instead of transverse, dead spaces within the tube region being avoided by gaps in the baffle placements where normally they would meet the header tube sheets. To accommodate the baffles, full spaces are created by leaving out horizontal rows of tubes where they would occur in the cross-baffled type. Also, the tube width of the boilers becomes narrower as the top of the header is approached, the general shape of the back header being as shown in the right-hand view, which illustrates a front half elevation of the front header within its enclosing steel casing. Thus there are 38 3-inch tubes in the lowest and only 24 in the highest full rows of tubes.

The standard boiler has a total heating surface of about 2500 square feet and 77.5 square feet of grate surface and is designed to withstand a working pressure of 200 pounds gage when complying with all the rules and regulations of the U. S. Steamboat Inspection Service applying to marine water-tube boilers for ocean and coastwise trade. Among special features it may be mentioned that the cover plates closing the holes opposite each tube are conical steel plugs, held in place by cup-shaped yoke plates and forged-steel nuts screwed upon threaded stems. The joints are made tight by means of copper ferrules, the inner edges of the handholes being rolled with a special expander to allow flaring of the copper ferrules. The plates therefore receive the pressure which tends to close the handhole openings, thus relieving the plate stem of the pressure load.

These boilers are equipped with the customary complement of fittings and trimmings suitable for marine practice and are fully steel encased outside of fire-brick lining.

Almy Water-Tube Boiler. In Fig. 75 is shown a front view of an Almy marine boiler, with its outside casing, grates, and fittings removed. It will be noted that the boiler is made up of straight malleable-iron tubes, connected by special fittings with one another and with manifolds at the bottom and top terminals. The sections that extend along the side from the bottom manifolds to the side top manifolds form a loop extending over above the fire so as to form the roof of the fire box. The sections arising from the rear bottom manifold form two loops, finally entering at the top front manifold. A flat continuous coil extending over the entire top is a heater section. The front top manifold is connected to a vertical steam dome, or separator, the lower end of which is riveted to a horizontal water reservoir extending across the front of the boiler. The steam connections are made at the top of the separator, while the water reservoir is connected by down flow pipes to the ends of the bottom manifolds in front.

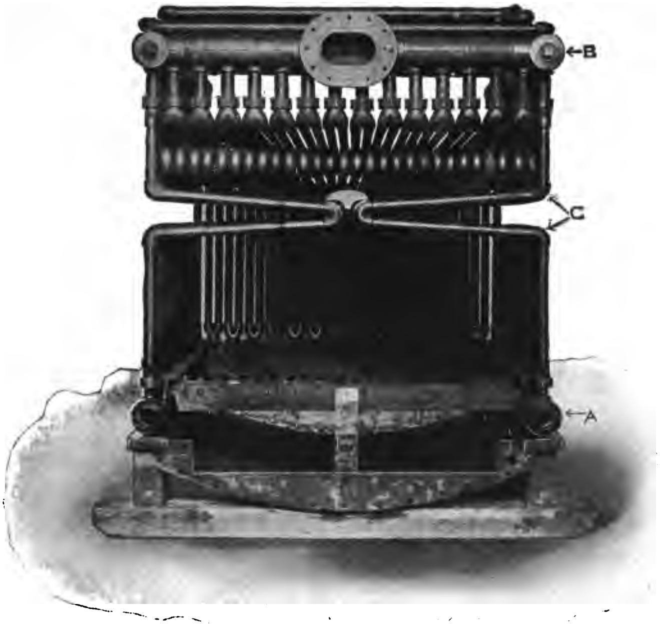


Fig. 75. Almy Sectional Water-Tube Boiler
Courtesy of Almy Water-Tube Boiler Company, Providence, Rhode Island

No baffling is placed inside the heating surface, the expectation being that the heated gases will envelop the tubes throughout. The particular characteristic of the boiler is the very large percentage of the heating surface that is in direct line with the radiant heat coming from the fire.

Double-Tube Type. This boiler is also made in what is known as the double-tube type, the expression in this case meaning that a double row of tubes following the same general contour is employed in place of one tube as shown in the illustration. This expression "double-tube" must not be confused with that employed elsewhere in this book where one tube is placed inside another.

Variations from Standard Land Types. The variations from standard land types of water-tube boilers are mainly those concerned with length of tubes and the use of cross-drums instead of longitudinal drums. Because the tubes are shorter they may be of smaller diameter as well, and the use of cross-drums is also permissible for the same reason.

Grate Area. The grate area is determined in a similar manner to that used in designing cylindrical boilers; but for most types the area must be greater, so that the heat may be distributed evenly over the surface of the tubes. It is not well to have the heat too intense near any of the tubes. The construction of most water-tube boilers allows some space above the fire for combustion.

Steam Drum. The size of the steam drum depends upon the amount of steam generated by the boiler. In order to make it as small and as light as possible, the boilers are sometimes worked at high pressure, and the pressure maintained constant at the engine by means of a reducing valve.

Water-tube boilers having the upper ends of the tubes opening into the steam space have dash plates and internal steam pipes which separate the water and steam.

Advantages over Cylindrical Type. Water-tube boilers have the following advantages over cylindrical boilers:

(1) Lighter (weight about one-half that of the cylindrical).
(2) First cost less on account of less material used.
(3) Less danger of damage in case of explosion.
(4) Large grate area and large furnace volume for combustion.
(5) Greater rapidity in raising steam.
(6) More easily placed aboard or removed.
(7) Have a larger capacity range.

The last three conditions are of great importance in the navy. As to the relative economy, there is much difference of opinion as the conditions vary considerably. In general, the economy is about equal in both types.

The ease of making repairs depends upon the type of boiler. The sectional type can usually be repaired more readily than others.

Disadvantages. These boilers have several disadvantages, among which may be mentioned the following:

(1) Tendency to prime.
(2) Difficulty of feeding.
(3) Sensitiveness to corrosion and dirt.
(4) Difficulty of repairing tubes.

These defects are reduced to a minimum if the boiler is of good design, well managed, and constructed of the best material.

Launch Boilers. The boilers used in torpedo boats, yachts, and launches should be safe, light, compact, and economical. Also, they should be capable of supplying dry steam at high pressures. Small vertical fire-tube boilers are sometimes used, but the water-tube boiler is better adapted to this work. The water-tube boilers already described are built in small sizes and generally give satisfaction. Perhaps the boilers most used for fast launches, yachts, and small vessels are the Ward and Mosher. These boilers are similar in general principles to most marine water-tube boilers but are made small, light, and compact.

BOILER DESIGN

FEATURES OF INDIVIDUAL BOILERS

As the advantages of employing high pressure and superheated steam became increasingly apparent and the sizes of the steam-using equipments became larger, boiler designers were compelled to exercise greater ingenuity and skill not only in order to create structures that would meet the two requirements just stated but also to overcome other difficulties created out of the means taken to afford larger and higher-pressure boiler units. As steam engineering became better understood, such features as internal circulation, effectiveness of heating surface, accessibility, repair or replacement facilities, sizes and shapes of tubes, etc., demanded closer attention. Without attempting to lay down all of the considerations in these several topics, it is believed well to illustrate and explain by typical examples the purposes aimed at by different designers.

CIRCULATION

Fire-Tube Boilers. The horizontal tubular boiler, illustrated in Figs. 11, 12, 13, and 14, being the most common of our fire-tube boilers, will serve as an example of the class with many fire tubes. and the considerations entering into its design will apply with equal force to the Scotch marine boiler illustrated in Figs. 21 to 25, inclusive. Where a large number of tubes are distributed through a boiler shell, it is now customary to locate the tubes so as to form wider lanes for the movement of steam and water than would prevail were the tube spacing uniform throughout. It is more important to provide these larger lanes for water travel in the case of internally fired boilers built after the pattern of the Scotch marines than in the case of horizontal tubular boilers. Experience teaches that unless such precautions are taken a definite water circulation is not set up and the tendency is to create dead zones within the water space, particularly in a boiler like the Scotch marine, which does not have hot gases impinging upon the outside shell. Fig. 23 shows plainly how extra spaces are provided between tube rows. While the primary reason for the spacing shown is to permit the construction of the combustion chambers in the rear, it is fortunate for circulation that they exist.

Water-Tube Boilers. *Overcoming Resistance to Water Flow.* The circulation within water-tube boilers constitutes one of the most important problems which they present, modern tendencies not only causing designers to avoid restrictions as much as appears to be necessary but also inducing them to afford positive circulation by inclining the tubes to a greater extent than at first would seem to be required. To illustrate this it is well to point out the precautions taken in two boilers of the horizontal water-tube type, representing the extremes of sectional and box-header construction. In Fig. 44 is shown in vertical section that portion of the B & W boiler which is likely to set up the greatest resistance to water flow. It will be noted that short 4-inch nipples connect the several vertical header sections to the boiler drum proper. In the illustration, twelve tubes of 4-inch diameter deliver the water passing through them through one 4-inch submerged nipple at the front throat; longer 4-inch tubes provide the facilities for keeping the boiler tubes supplied with water coming from the rear end of the drum. Manifestly, the flow of water, supposing it all to be solid, through the nipples must be twelve times as rapid as the average flow through any single tube. Turn now to Figs. 48, 49, and 50.

In these are shown the details of construction of Edge Moor boilers in the particular place known as the throat and previously dealt with in B & W boilers. In this instance no nipples are employed. The depth of the water leg is about 1 foot; then, supposing the Edge Moor boiler is also twelve tubes high, the space available for water movement on the way to the drums is an area of about 78 square inches as against about 12 square inches for the B & W boiler. There is this difference between the two boilers: the B & W boiler is pitched 2¼ inches to the linear foot, whereas the Edge Moor boiler tube pitch is 1 inch to the foot; consequently, while the B & W boiler may set up a greater resistance to circulation, it also provides what is believed to be a correspondingly greater force to overcome it.

Prevention of Moisture. Some types of boilers, mainly the vertical or semivertical, provide extraordinarily large circulation facilities and sometimes do so to such an extent that the space into which the tubes discharge may be in a constant condition of very active ebullition. If the water tends to foam, this violent stirring accentuates the trouble and additional means must be provided to afford space and time for the water thrown up into the steam space to settle back to the general level. Baffles are provided to receive water and steam impingement, thereby causing the water to lose its velocity while the steam may pass to an additional drum for further separation. The Stirling boiler, Fig. 62, is a good example of this arrangement.

Auxiliary Circulating Pipes. It is sometimes necessary to provide special circulating pipes leading from one drum to another or from the upper steam drum to a lower water drum, as in Fig. 61. This is done because all the tubes of the boiler are intended to carry water and steam upward to the steam drum, thereby affording no way for the water to reach the lower drum except by setting up a counter-circulation resisting that set up by heat transmission. To facilitate the circulation, therefore, the pipe column shown on the left of the illustration is installed and all downward movement of water may take place through this.

Importance of Good Circulation. *Features of Boilers Affected.* In general, the matter of circulation affects two of the most important features of boilers. If the circulation is inadequate, it is reflected in the inability of the boiler to absorb heat readily and, fully as important as this, in the material curtailment of the life of the parts subjected to heat. This is due to the fact that steam pockets are created on the water side of the heating surface and, in as much as steam is a poor absorber of heat as compared with water, the plates will not transmit the heat to the steam as rapidly as though solid wetness were presented to the plate; hence the metal may become overheated. If the circulation is such as to permit the alternate but rapid formation of steam pockets followed by solid wetness, fatigue of the metal is set up and crystallization ensues. The deterioration under such circumstances is very rapid.

Retirement of Old Forms. It is this one matter of insufficient circulation that has caused in modern boiler practice the retirement of many of the old forms which formerly were well received. Where a high rate of duty is expected regardless of what the character of water may be, a boiler such as that illustrated in Fig. 68 is out of the question. The same comment can be made with reference to Fig. 70, even supposing the materials would withstand modern high pressure and in other respects be satisfactory.

EFFECTIVENESS OF HEATING SURFACES

Heating Surface Problem Difficult. Manifestly no good purpose is served by providing useless heating surface, yet the problem of using all the heating surface provided is not as simple as it may appear. Out of the accumulated experience of boiler builders, designers, and users has come a fairly good understanding of what are the main items to be considered in employing the heating surface properly so that injury in some other particular may not be encountered. Referring to Fig. 41, it will be noted that the boiler is baffled by the placement of two vertical flame plates located transverse to the tubes. It is recognized in this instance that possibly the upper portion of the top rows of tubes near the front headers may not be well employed as heating surface. The same remark applies to a less extent to the bottom rows of tubes in the second and third gas passes. Were expedients adopted to employ these tubes throughout their length to their fullest extent, then so much resistance to the draft forces would be set up that the furnace end of the installation might suffer. It is true also that the advantage of having gases leave the boiler setting near the top rear influences the design of setting. In the special setting shown in Fig. 48 the attempt is made to utilize the heating surface more effectively by the employment of four passes instead of three. The design undoubtedly accomplishes this purpose but does so at the expense of creating a materially larger draft loss in the boiler-tube region as compared with a more open system of baffling, which effect, being foreseen, is met by using longer tubes than normally as well as by providing greater chimney or fan draft facilities.

Designers of settings do not all agree as to the means that should be taken to accomplish the same effect. The inclined baffle tile and baffle ledges leaning against or adjacent to the tube banks of the boiler shown in Fig. 63, are manifestly installed to cause the gases to travel closely within the tube regions. The boiler illustrated in Fig. 67, not having such ledge baffles permits the gases to seek the lanes not filled with tubes.

In Fig. 61 is illustrated a design that may become ineffective on account of the failure of parts. In this case the two conical baffle rings placed within the center tube cone may burn out, thereby allowing the gases to pass directly to the chimney without further encountering heating surface.

Where the gases have an opportunity to accept a choice of paths, it is seldom possible to make all the heating surface effective, but it is important to avoid two or more paths which the gases may take through the heating surface on their way to the chimney.

Refer now to Fig. 52. If this boiler is so designed on account of space considerations that it becomes relatively high in number of tubes and narrow, then the vertical distance between the upper and lower baffles is too liberal for the gases generated in the furnace and the tendency is for them to travel across the tube chamber without coming into intimate contact with the tubes throughout their length. Such a boiler is faulty in tube arrangement, yet the design may be amply strong and good in all other particulars.

The effectiveness of heating surface is often destroyed by the creation of pockets within the tube chambers in which large quantities of soot and fine ashes may accumulate without being readily displaced. Such a trouble is accentuated by the fact that, when a pocket exists, gas circulation within the pocket is of low velocity and the means taken for the blowing out of soot becomes ineffective because the gases, moving slowly, permit the soot to fall back after being stirred up. In other words, there is no special difficulty in removing soot where the gases travel with high velocities, but it is almost impossible to remove it unless there is a swift-moving current to carry it after it has been dislodged.

Absorbtion of Heat by Radiation. The most effective heating surface that can be obtained is that which is in the direct line of radiant heat coming from the fuel bed. It is this peculiarity of the heating surface of the externally fired shell boiler that has retained this type in such general use as to constitute for moderate pressures the most common boiler met with. In this instance the boiler shell is located immediately above the fire and the transmission of heat through the relatively thick shell metal, even when internal circulation is not especially good, is very rapid. Fire-box boilers are a still more striking example of the rapidity of radiant heat absorption. Those boilers of the water-tube type that present large quantities of heating surface to the radiant heat action of fires are invariably more economical steamers than those which are not so liberally provided with heating surface within range of radiant heat. Unfortunately the very causes of a high rate of radiant heat transmission sometimes set up difficulties in other particulars, among which may be mentioned the likelihood of forming steam pockets due to faulty circulation, which in turn may cause tube failures to an excessive degree.

ACCESSIBILITY

Provisions Usual for Inspection and Cleaning. Under this topic the main problems are those of the plant designer rather than of the boiler designer. There are practically no manufacturers of special boiler equipment that do not provide facilities for internal cleaning or inspection of pressure parts. The facilities may be crude or require much effort to employ them, but they are present. It is important in selecting a boiler to look into these matters and, if a choice is permitted, to select the ones wherein the least manual labor is required during operation. An important instance is that of choosing for water-tube boilers the kind of a handhole cover plate which does not depend too much upon the skill of the operator to make a tight joint when closed. In other words, it is advantageous to select a plate that has the pressure of the steam forcing it against its seat rather than the reverse, not only to reduce the hazard but to reduce the labor and time out of service.

In general, cover plates should be selected that have their pressure loads symmetrically distributed. Odd shaped plates requiring complicated forms of gaskets should be avoided, unless some very decided advantage in some other particular is created by their use.

It is usually less trouble to remove one manhole plate giving access to a whole bank of tubes than to take off as many plates as there are tubes. This is not always an advantage, as the mere taking off of the plate does not complete the job and as in most instances where a manhole plate is taken off in order to make the tubes accessible a man must enter the drum, which imposes the further necessity that the drum be cool and free enough from vapor to permit him to enter to perform his work.

Replacement of Tubes. *Facilities in Boiler Itself.* It is important that any part which may fail, such as a boiler tube, be removed and replaced without disturbing too many other boiler elements. The Stirling boiler is an example of one where tube placing is such that even the most remote or interior tube can be passed out from its nest without getting down other tubes. The practice of so designing boilers is becoming quite general and is to be commended unless carried so far that the gases do not have a fair attack at the heating surface.

Space Facilities. In designing or installing a boiler the only safe assumption is that any one of the tube elements may fail and require replacement. For this reason not only must the boiler permit having its tubes replaced but spaces surrounding the boiler must also be provided. For instance, a straight-tube boiler like the horizontal water-tube types will require a space in one direction, either front or back, equal to the length of the tubes. The same remark applies to any of the fire-tube boilers, such as the horizontal tubular and the Scotch marines. To replace the tubes, the boiler illustrated in Fig. 47 must have a space covering a rather large horizontal area. Some forms of vertical boilers require almost double the installation height in order to replace tubes without wrecking the boiler setting.

SHAPES AND SIZES OF TUBES

Straight vs. Bent Tubes. It is always desirable to retain tubes in a straight condition as manufactured instead of bending them to some particular shape, since the user need not carry in reserve a number of different shapes and it is also easier to inspect and clean them. It does not follow, however, that a bent-tube boiler is necessarily less to be desired than a straight-tube boiler, for it is more than likely that the bent-tube boiler may be better able to accommodate itself to the space in which it is to be located.

Tube Diameters. *Fire-Tube Boilers.* In the matter of tube diameters there is less freedom of choice than as to shape. If the boiler is of the fire-tube type, then the diameter of the tube plays an important part in the matter of draft reduction. The locomotive boiler is a good instance of the use of tubes of small diameter being made possible by exceedingly high draft created at the exhaust nozzle. If the attempt were made to apply locomotive tube practice to stationary practice it would be found impractical because the tubes would be too small, would rapidly clog up with soot, and even when clean would impose too much of a restriction. In general, the longer the fire tube, the larger its diameter needs to be.

Water-Tube Boilers. In water-tube practice, tubes of small diameters are not suitable in that the application of intense heat tends to create steam pockets within them, because the circulation forces cannot overcome the water flow resistance. Tube failures due to overheating, fatigue, or scale formation may combine to make their cost prohibitive.

It is a fair statement that the greater the rate at which the boiler-heating surface is expected to operate the larger should water tubes be; also, the longer the tubes the larger the diameter. The reverse is partially true with respect to fire tubes, and in this instance the practical limitations are those set up by the available draft.

PLANT FEATURES INFLUENCING BOILER DESIGN

Analysis of Problem. While it is impossible to take note of the many items that must be considered in the problem of designing steam generating plants, it is not out of place to indicate briefly the salient considerations. In presenting a few of the most vital elements of boiler plant design the most intimate association of the several topics or divisions of the subject is presupposed, it being inevitable that the elements of water, fuel, steam demand, etc., are closely interrelated so far as influencing the type and size of boiler units is concerned.

As a fundamental truth it may be stated that all types of boilers that have withstood the test of time service can, in general, be made to give practically the same economy of service, provided the features external to them are selected with good judgment. By external features are meant tight settings, good boiler water, adequate draft, etc.

Personal Element. The reader must, however, bear in mind that whatever the intention of the designing engineer the performance of the equipment depends upon the one person or group of persons who operate it. In other words, a prime requisite is that the equipment shall be of such a character that the labor service available is able to grasp the possibilities offered by the plant; therefore, if the plant steam output demand is not large enough to warrant the engagement of highly skilled operating engineering, then, of course, it shows decidedly poor judgment to select equipment of a nature effective only with expert manipulation.

Size of Plant. Where the steam demand requires the installation of more than one unit, the problem is sometimes quite difficult. In general, it is usually not good practice to select two units instead of three of the same aggregate rating. On the other hand, it is not as economical, either as to first cost or later operation, to select many small units in place of a relatively few large ones. Where a choice is permitted, the plant designer should aim to provide an additional stand-by unit or the space in which one may be placed. In the latter event, provision should be made to permit the addition of the breeching and other boiler room facilities without disturbing the character of the original installation.

Stokers. The size of the boiler units as well as their number determine the feasibility of installing stokers. The latter are not usually serviceable or economical when combined with boilers of less than 150 horsepower. Some types of stokers do not become economically worth while until the sizes both of the units and of the plant as a whole become quite large, the character of labor required for operation and their cost being against the use of the most refined stokers unless the plant has a large output. The nature of the available fuel determines the type of stoker that can be used economically and by learning the economical size of the stoker of that type in common practice the plant designer may come to fix upon boiler sizes somewhat different than he would select if not considering stokers. If stokers are justified by other considerations, the boiler design must be made to fit, by which is meant that the dimensions of boilers of any given make may vary to suit furnace size and shape. Also, the boiler baffling may require modification to get satisfactory results.

Water. One of the troublesome elements in many cases is the character of water that is available for plant use. If the water precipitates a very hard scale, then it is usually best to treat it before admitting it to the boiler, but even with such precautions there are occasions when some scale will appear. If the scale so formed cannot be completely eliminated by treatment, the engineer is likely to be justified in ruling against the adoption of water-tube boilers, though, no matter what the type of boiler, scale of this character is likely to cause trouble. Or, he may be justified in rejecting a water-tube boiler in which the labor of making the tubes accessible for cleaning is much greater than in a boiler of another type; for instance, he may choose a vertical or semi-vertical water-tube boiler in place of a horizontal water-tube boiler having a multiplicity of handhole plates. It is to be said, however, that unless the water contains common salt in solution there is hardly any reason why water treatment will not permit the greatest freedom in the selection of the type of boiler. Where the available water is unsatisfactory, a water-treating equipment of good design is always a paying investment, no matter what type of boiler is selected.

Fuel. Aside from grate sizes and character, it is extremely important that the nature of the available fuel be considered in connection with the type of boiler selected. In the most favorable furnaces, soot or fine ash is bound to develop at the grate and pass to the heating surface where large portions may deposit. Since dirty heating surface on the fire side is more costly in fuel than any other form of boiler uncleanliness, if the fuel itself contains a relatively large percentage of volatile or soot-making matter, then the engineer should select a type of boiler in which the places of soot lodgment are easily accessible. For instance, a three-crosspass horizontal water-tube boiler affords less opportunity for soot deposit in the tube chambers than a horizontal boiler with horizontal passes. In any event, soot removing demands close study in all stages of the boiler plant design, consideration being given to the furnace, the boiler passages, and the spaces around the boiler settings, keeping in mind that the nature of the coal has a direct bearing on the amount of such deposits. Thus the kind of fuel determines to a large extent the kind of stoking or firing equipment which, in turn, fixes the size and shape of the boiler.

Available Space. Aside from the very obvious necessity of choosing boiler units that may be installed within the space assigned to them, there are less obvious factors that need consideration. The fact that an installation may be made does not argue that it is necessarily good, as is attested by the thousands of instances where sacrifices to space considerations were made in the first instance for unimportant reasons. If it is remembered that a boiler is only an absorber of heat and that there is also the problem of heat generation, little difficulty is encountered in understanding the reasons for the following points:

(1) Under no circumstances compromise with the question of providing combustion time and space. If the head room is cramped, make it up by selecting a type of boiler that gives at least ample horizontal room. A reverse situation demands opposite treatment.

(2) Sufficient draft combined with furnace design determines the rate at which the fuel may be burned as well as the economy of heat evolution. A boiler design that does not lend itself to the chosen space without sound breeching design should be rejected. Linked up with this is the whole subject of boiler baffling. When designing a new plant create (by overprovision, if possible), all the draft intensity that may be desired. If looking

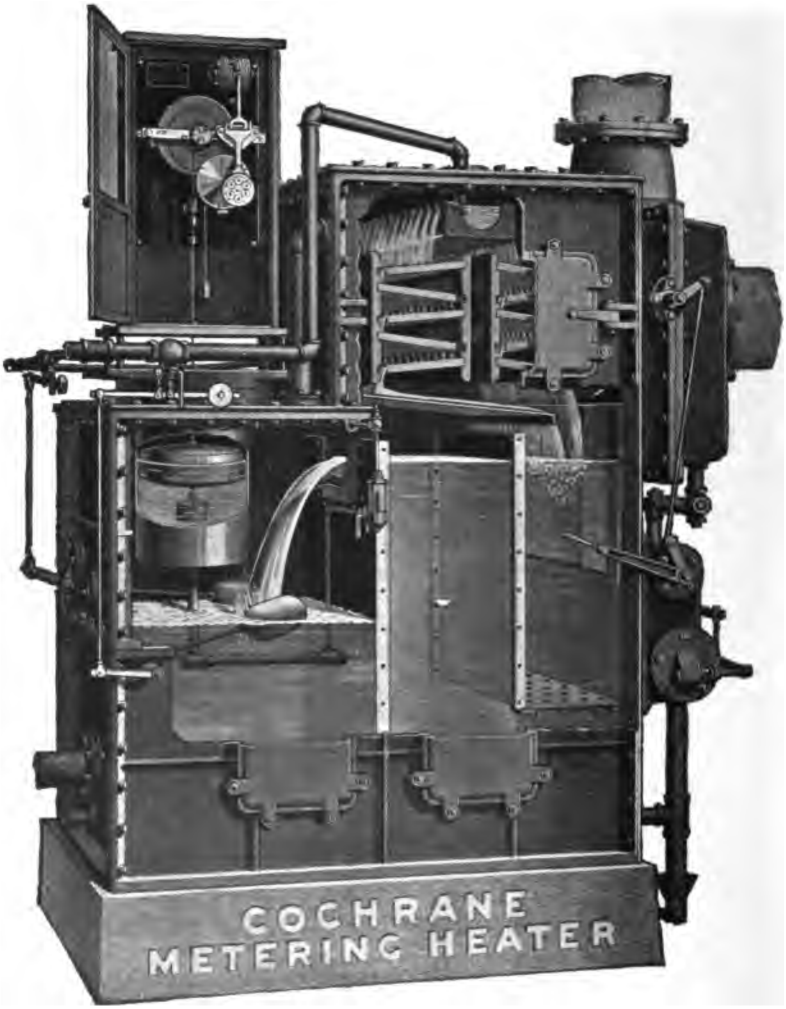
for trouble in an existing plant, it will probably be found by an analysis of the draft facilities. The sizes of gas passages and their relative positions and shapes are among the important items.

(3) Do not overlook tube replacement facilities.

(4) Soot removal, whether done manually or by permanent blowers, demands adequate alley ways around boiler settings. Many forms of stokers require side inspection and manipulating space. No other condition is so disagreeable as cramped quarters for routine boiler and furnace operation. In order to get adequate space it may be necessary to reduce setting widths and increase boiler heights when choosing them, but it is usually worth while to do so unless some other important feature is adversely affected.

(5) It is a mistake to install more than two boilers in a single setting, and, where done by choice, the reasons for so doing should be of the best and it should be fully appreciated that sacrifices will be made during the life of the plant.

(6) Many boilers properly designed as to pressure parts fail to be fully effective because of faulty supports, poor baffles, improper expansion provisions, etc., all of which are reflected in the creation of cracks in settings attended by uneconomical heat absorbtion, reduced capacity, and high furnace maintenance costs. This part of the subject warrants the closest study in even the most minute details.



PART SECTION OF COCHRANE METERING HEATER
Courtesy of Harrison Safety Boiler Works, Philadelphia

BOILER ACCESSORIES

INTRODUCTION

A proper consideration of the subject of "Boiler Accessories" presupposes the reader to possess a fairly complete understanding of the purposes for which boilers are used, and of their main characteristics as to design and arrangement. In order to operate a boiler successfully many devices have been developed. Some of these devices are primarily concerned with the routine operation of the boiler and are those which make it possible to operate it at all. Many others are used in conjunction with boilers with the purpose of promoting a more economical performance, although these same devices may also contribute to greater safety. In the present treatment it is thought best to deal with the several items of the subject by taking up first the parts which have to do with the *pressure,* that is, with all of the devices which are included in the steam and water side of the steam-generating system, thus leaving the devices used in the generation and delivery of heated gases to be treated in the last part of this paper.

BOILER ATTACHMENTS

MANHOLES AND HANDHOLES

Characteristics of Manholes. A manhole allows access to the boiler for cleaning and repairs. It is elliptical in form and large enough to admit a man. About 16 inches for the major axis, and 12 for the minor axis, is a good size. The manhole is closed by a plate or cover made of cast iron or forged steel. This plate is held to the seat by a yoke, or yokes, and bolts, the pressure inside of the boiler pressing the plate against its seat. Fig. 1 shows one form, *Y* being the yoke, *L* the cover, and *N* the bolt. The joint between the cover and the shell is made steam tight by packing.

Reinforcing Plates. The strength of the boiler should always remain unimpaired; so, whenever a large hole is cut in the plate, the edge should be strengthened, for the tension is concentrated there, and the plates, moreover, are likely to become weak by corrosion. The strain put upon the plate by screwing up the cover, if no packing is used, is considerable, especially if a piece of scale gets between the faces before the joint is made tight.

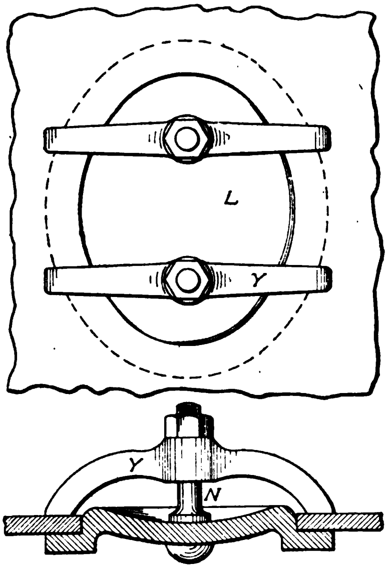


Fig. 1. Plan and Section of Manhole Cover

Fig. 2 shows the section of a strong and simple manhole. The edge of the plate is strengthened by a broad ring of steel, which is flanged and riveted to the shell, its edge forming the seat. The cover as shown in the figure is shaped for strength. The edge of the ring which forms the seat, and the cover, are machined to make a tight joint without packing. The strengthening ring should be at least ⅝ inch thick and 4 inches wide, so that the rivet holes may not be too near the edge.

Location. In some types of boilers, such as horizontal water-tube boilers, when it is possible to place the manholes in the ends of the drums, the elliptical opening is flanged in and a reinforcing ring is shrunk around the flanged metal for strength, and then both the edge of the flange and the face of the reinforcement are faced off to provide a true seat for a gasket between the seat and the manhead.

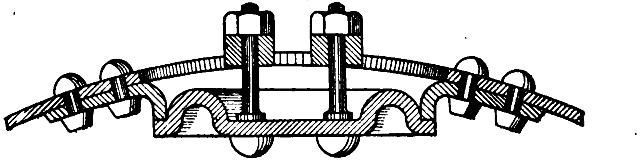


Fig. 2. Section of a Strong but Simple Type of Manhole

It is important to note that the major axis of the manhole should be so placed that the removal of the metal weakens the structure as little as possible. In shell boilers, if the manhole is placed on the cylindrical part, the major axis is placed in the same direction as the girth seam because the danger of rupture due to internal pressure is only half in girth what it is longitudinally.

Use of Handholes. Handholes are commonly placed in boilers to give access to parts where a man cannot enter; for instance, in many horizontal return-tube boilers there may be a handhole in each end near the bottom. They are convenient to admit hose for washing out the boiler and for the removal of scale and sediment. Handholes are similar to manholes in construction, but usually require only one yoke and one bolt to keep them in place. Handholes greatly facilitate cleaning the fire-box water leg of locomotive and small vertical boilers.

Individual and Group Handholes. The development of water-tube boilers has brought about a great variety of schemes for giving access to tubes for their renewal and cleaning in such cases where the tubes are expanded into headers or manifolds not large enough to admit a man (Fig. 50, "Types of Boilers"). Provision is usually made for access by providing a hole opposite each end of the tube. These holes are not always elliptical but may be circular, provided the plates can be removed from the boiler head at some other location. In one type, the plate which makes the closure is placed on the outside of the opening, with the yoke on the inside, thus compelling the plate to resist the pressure in lifting it from its seat. In this case no gasket is used in the joint, but dependence is placed upon ground joints both where the plate meets the seat and where a blind nut presses against the plate to hold it in place.

Some water-tube boiler designers try to overcome the difficulties of having separate holes for each tube by having handholes large enough to serve groups of tubes; others provide separate holes for each tube, but shape the handhole slightly different than elliptical in order to obtain the advantage of interchangeability having the plate on the inside of the header or box. In fact, the problems arising from the necessity of providing access to tubes have given rise in their solution to a great variety of boiler designs, in many cases determining the main features which enter into boiler construction.

SUPPORTS

Importance of Adequate Supports. Since a boiler is constructed of heavy materials and contains a great deal of water, and at the same time is subjected to high and varying temperature stresses, it should be carefully supported. It is not good practice to depend upon masonry above the fire line for holding the boiler in position, though of course this is permissible, if the operating conditions are not severe, and if due diligence is practiced in the inspection of the brickwork after a good design has been selected. Not a few severe boiler explosions have been attributed to improper supporting designs. This is especially true in cases of boiler and pipe failures where boilers have settled, thus drawing heavy steam piping of a rigid form down with them.

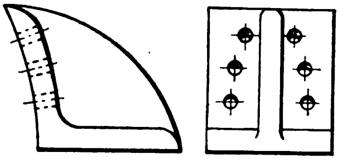


Fig. 3. Boiler Bracket with Rivets All Above Flange

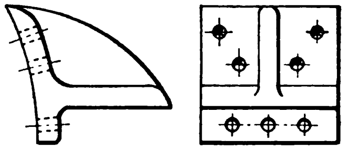
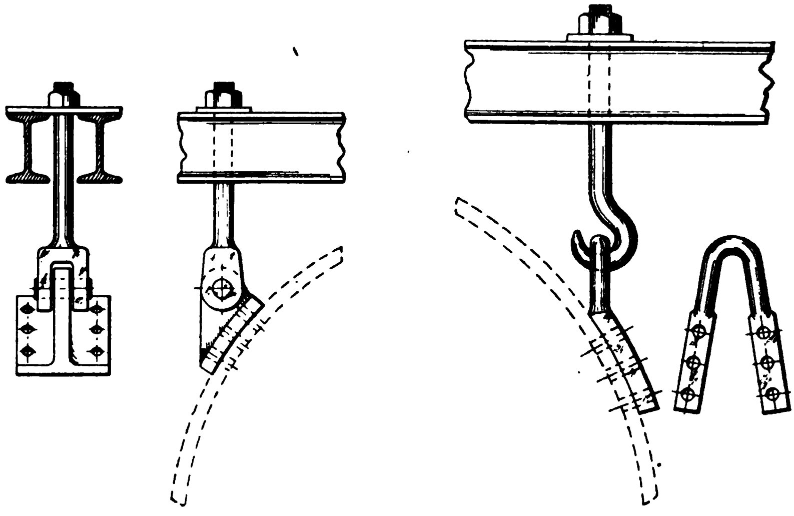


Fig. 4. Boiler Bracket with Rivets Above and Below Flange



Figs. 5 and 6. Two Methods of Supporting Boilers by Suspending from Overhead Beams

Types of Construction. There are two common methods of supporting boilers: (1) by means of brackets; (2) by suspending from beams.

Bracket Supports. In horizontal tubular boilers it is customary to use two brackets on each side. The front brackets rest on the brickwork, but the others rest on small iron rollers to allow for expansion. Brackets are so arranged that the plane of support will be a little above the middle of the shell. There are several forms of brackets. The form shown in Fig. 3 is usually made of cast iron and is provided with rivets above the flange of the bracket. It is better to have the rivets both above and below the flange, as shown in Fig. 4.

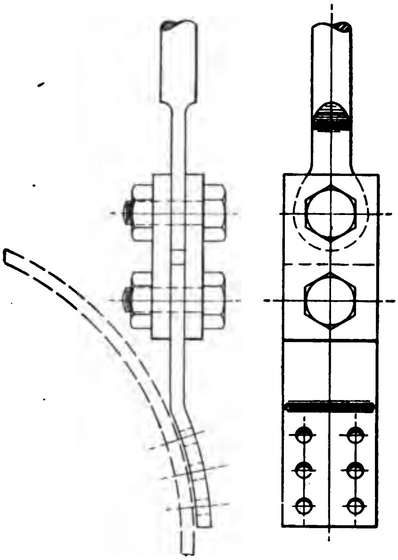


Fig. 7. Flexible Support for Suspended Boiler. Flexibility Secured by Means of Two Pieces of Boiler Plate Bolted Together

Suspension Supports. Fig. 5 shows one method of suspending from beams. A lug made of wrought iron is riveted to the plates of the boiler. A bolt having one end bent like a hook holds the lug from the beam. In Fig. 6 the lug is replaced by a loop of wrought iron. Fig. 7 shows another method of suspension, the connection between the rod and the boiler plates being short pieces of boiler plate arranged for flexibility.

When the boiler is of small diameter, it may be suspended as shown in Fig. 8.

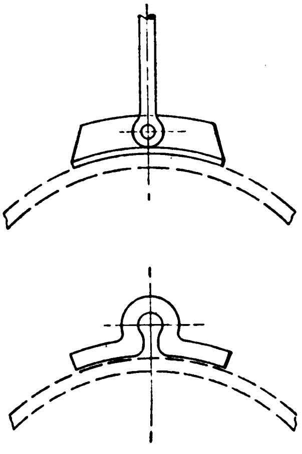


Fig. 8. Illustrating Methods of Suspending a Boiler of Small Diameter

Water-tube boiler supports are as numerous as the types of boilers manufactured. The tendency is to provide a form of support which permits the erection of the entire boiler before constructing any of the enclosing masonry. Suitable facilities must be provided for the expansion of the boiler proper by leaving space between the boiler and the masonry, which is filled in with some more or less pliable material, such as mineral wool, which at the same time will exclude air from entering the setting.

FUSIBLE PLUGS

Necessity for Use. Fusible plugs are used as a safeguard against the effects of carrying water at too low a level in the boiler. They are especially serviceable in such cases as they provide a warning when the water over the crown sheet of a fire-box boiler becomes too shallow. The best municipal and government regulations include requirements stating exactly the form and position of plugs on all kinds of boilers; these regulations, if carried out as intended, are of considerable service although it must be understood that too much reliance should not be placed upon a device of this character.

Types of Plugs. There are two main forms of fusible plugs: those which on blowing out require the immediate shutting down of the boiler, and those which act as a warning only, being capable of replacement without shutting the boiler down. The tendency of practice is to allow only the first kind, and also to avoid the use of valves which may shut off the escaping steam after a plug has blown out. The latter remark applies to the form of fusible plug which is in communication with a pipe projecting below the water line, a type frequently used in the drums of water-tube boilers. These plugs consist of a core composed of an alloy of tin, lead, and bismuth, with a covering of brass or cast iron. The United States inspection law requires at least one fusible plug to be put in every marine boiler, with the exception of water-tube boilers, the plug to be made of a bronze casing filled with good quality Banca tin from end to end. While this plug is kept at a comparatively low temperature by water on one side, the fire on the other side will not melt it; when the water level becomes low enough to leave one end of the plug uncovered, the alloy core of the plug, having a comparatively low melting point, will fuse and run out of its casing, thus relieving the pressure in the boiler and allowing the excess of steam to extinguish the fire, which otherwise would be likely to destroy the crown sheet.

Unreliability. Fusible plugs are frequently unreliable. Sometimes they will blow out when there is no apparent cause, and sometimes remain intact when the plates have become overheated. If a coating of hard scale is allowed to accumulate over the plug, it may stand considerable pressure even after the core has become melted. To provide against this, the plug should be replaced frequently. If allowed to remain in the boiler for any length of time, the composition of the alloy is likely to change, the plug thus becoming more or less unreliable.

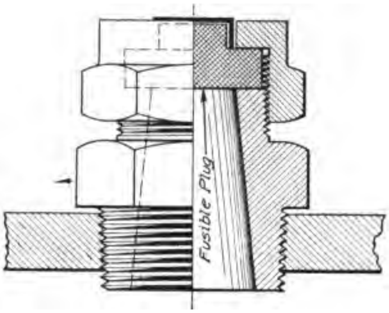


Fig. 9. Part Section of Fusible Plug Attached to Crown Sheet of Boiler

Construction. Figs. 9 and 10 illustrate the ordinary plug. It should be so made that, when screwed into the crown sheet, it will project 1½ or 2 inches above the plates, so that when the alloy melts there will be a sufficient depth of water over the
to prevent injury from heat.

.. Low-Pressure Gage

Sometimes the core is co·
taken up by a hairspring. Fig. 12 shows
in Fig. 9, which prot
..nd face of a Bourdon steam gage manufactured by
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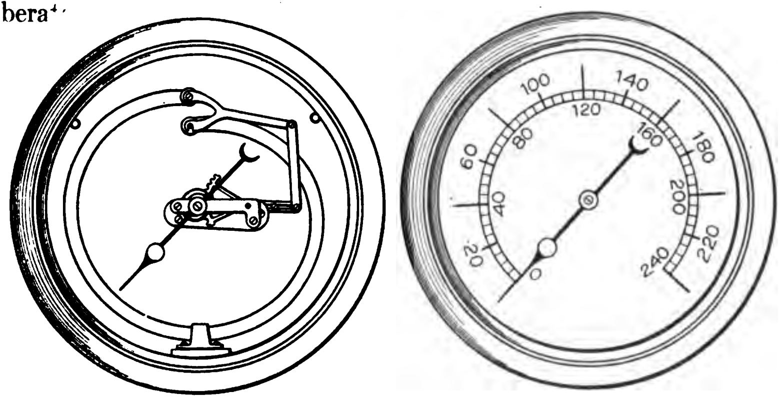

Fig. 14. Steam Gage for Use on Locomotives. Excessive Vibration of Needle Prevented by Use of Two Short, Stiff Springs

Fig. 13 shows the exterior and interior of a steam gage. The face of the dial is graduated. The only difference between this gage and a vacuum gage is that in the latter the curved tube is of the boiler, and those [illegible] of replacement without shutting the [illegible] ency of practice is to allow only the first kind, [illegible] the use of valves which may shut off the escaping steam [illegible] plug has blown out. The latter remark applies to the for[illegible] fusible plug which is in communication with a pipe projecting be[illegible] the water line, a type frequently used in the drums of water-tube boilers. These plugs consist of a core composed of an alloy of tin, lead, and bismuth, with a covering of brass or cast iron. The United States inspection law requires at least one fusible plug to be put in every marine boiler, with the exception of water-tube boilers, the plug to be made of a bronze casing filled with good quality Banca tin from end to end. While this plug is kept at a comparatively low temperature by water on one side, the fire on the other side will not melt it; when the water level becomes low enough to leave one end of the plug uncovered, the alloy core of the plug, having a comparatively low melting point, will fuse and run out of its casing, thus relieving the pressure in the boiler and allowing the excess of steam to extinguish the fire, which otherwise would be likely to destroy the crown sheet.

Unreliability. Fusible plugs are frequently unreliable. Sometimes they will blow out when there is no apparent cause, and some-free end is multiplied and indicated by a needle, which is attached to the pinion. The needle moves over a dial which is graduated to agree with a mercury column, or with a standard gage. The

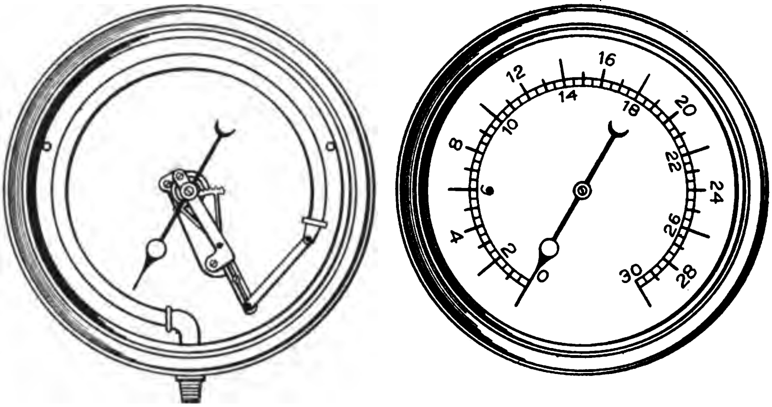

Fig. 13. Interior Mechanism and Dial of Low-Pressure Gage

backlash of the levers is taken up by a hairspring. Fig. 12 shows the interior and face of a Bourdon steam gage manufactured by the American Steam Gage Company.

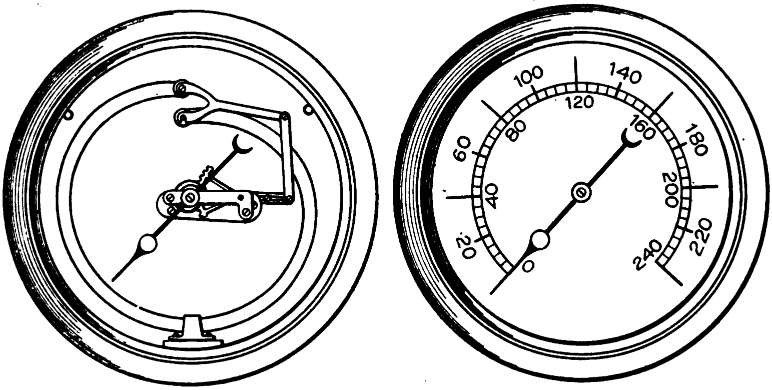

Fig. 14. Steam Gage for Use on Locomotives. Excessive Vibration of Needle Prevented by Use of Two Short, Stiff Springs

Fig. 13 shows the exterior and interior of a steam gage. The face of the dial is graduated. The only difference between this gage and a vacuum gage is that in the latter the curved tube is turned in the opposite direction, so that the needle will move clockwise with a decrease of pressure.

Locomotive Steam Gages. On account of the jarring, the gage for locomotives must be very strong. To prevent excessive vibration of the needle, two short, stiff coil segments are used, as shown in Fig. 14.

Use of Testing Gage. Sometimes two pressure gages are fitted to a boiler; one indicating the working pressure, and the other graduated to about twice the working pressure. The latter is useful in testing the boiler under water pressure, and also serves as a check on the other. The pipe which connects the pressure gage to the boiler should have bends in it near the gage. These bends—or, better, a coil pipe, as shown in Fig. 15—are filled with water, which transmits pressure and keeps the spring at a nearly constant low temperature. Gages should be placed where the water in the coiled pipe will not freeze; also, the gage should not be exposed to a high temperature. In order that the gage may be removed from the boiler for examination, repairs, or calibration, while the boiler is under pressure, the connection should be provided with stopcocks.

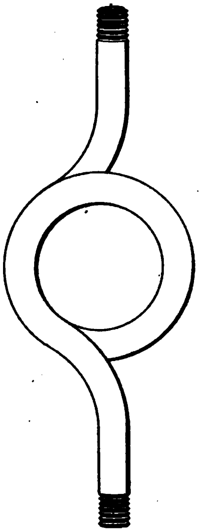

Fig. 15. Water-Filled Coil Pipe for Connection to Steam Gage

In a battery of boilers, each should have its pressure gage, which should be connected directly to the boiler, not to the steam pipe.

Special Features. For stationary practice many kinds of gages are manufactured, but the principle of operation is always the same; the differences are mainly in the accuracy of the indicators and in the enclosing cases. To make the dials more easily read lights are sometimes placed behind the dials so as to shine through, thus bringing the figures out distinctly; these are termed illuminated dial gages. To preserve the accuracy of the instrument the mechanism is usually enclosed in a dust-proof case. Where the distance between the observer and the dial is considerable, the dials should be large in diameter and the figures made very distinct.

WATER COLUMNS

Description. A water column is a boiler attachment used for the purpose of determining the level of the water. A complete column consists of a cylindrical chamber, Fig. 16, in direct communication with the boiler in two different places, viz, the steam space and the water space, carrying on one side, with connections in the upper and lower parts of the cylinder, a glass tube called a *gage glass*, three quick-opening cocks in direct communication with the interior of the column cylinder at three levels, and a spherical enlargement beneath the column which is intended to provide a place for sediment collection. Exterior connections to both the column proper and the gage glass, containing valves to permit blowing down, are also essential.

In certain types of boilers it is more convenient to attach the gage cocks and the gage glasses direct to the boiler sheets without the use of an independent column. The principle of operation and use of the separated attachments is, of course, the same as though the column were used. The advantage of the column is that it reduces the number of openings in the boiler proper, and by its use a number of other attachments are made possible. The latter remark refers to high and low water alarms, feed-water regulator attachments, etc.

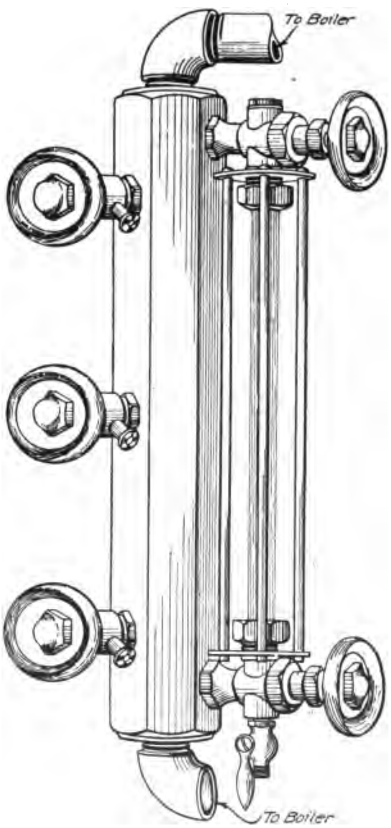

Fig. 16. Water Column Carrying Gage Glass and Try Cocks

Alarm Systems. When a water column carries an alarm system, the usual method is to provide floats in the cylindrical portion of the column which, upon being displaced from their normal positions, open needle valves leading to whistles. The normal positions of the floats cover a range of water height within which the boiler can be safely operated; when the water is either above or below this height, one or the other float opens its valve and a shrill whistle calls the attention of the water tender. There is a difference of opinion as to whether or not shut-off valves should be located in the pipe lines joining the water column with the boilers above and below the column. Such valves are of service when it is desired to replace a broken gage glass—should better means be lacking—or to perform some other kind of a repair while the boiler is under pressure. Municipal and state regulations are gradually recognizing that it is better to object to the use of such valves, as there is danger of their being closed when not so intended and thereby greatly increase the hazard. In any case, if these valves are used, facilities should be provided for locking them *open.* The pipe work in making water-column connections should be such as to permit access throughout without difficulty; this is accomplished by the use of straight pipe connected up with *crosses* and *tees.*

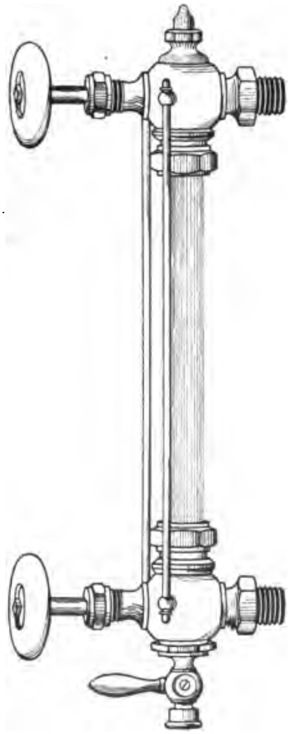

Fig. 17. A Good Type of Water Gage Glass

Gage Glasses. In order that the fireman may know the water level without trying the cocks, a water-gage glass is used. It consists of a strong glass tube about one foot in length, having the ends connected to the boiler or column by suitable fittings.

As both ends of the tube are in communication with the boiler, the water level in the glass will be the same as in the boiler, and is always in sight when properly connected. Fig. 17 shows a good form of gage glass. The glass is protected by rods which are parallel to it. As the glass often needs cleaning, repacking, or renewing, cocks are provided for shutting off communication with the boiler. A drain cock is also placed at the lower end to empty the glass when the attendant wishes to ascertain whether or not the glass is working properly. The drain cock is often provided with a drain pipe. The steam and water passages should be at least one-half inch internal diameter.

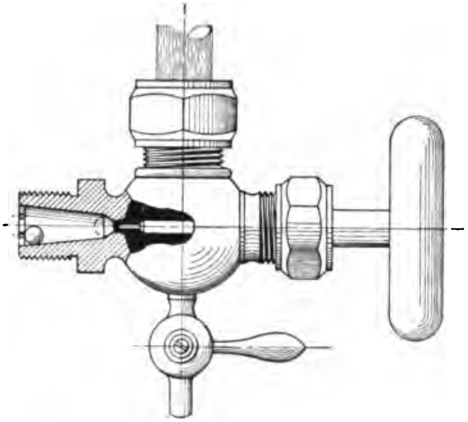

Fig. 18. Automatically Acting Ball Valve to Prevent Injury to Workmen and Loss of Water on Breaking of Gage Glass

Precautions in Case Gage Glass Breaks. The glass is likely to break because of accident or of changes in temperature. To prevent serious injury to the fireman and loss of water as a result of the breaking of the gage glass, automatic valves may be placed in the passages. In Fig. 18 a ball valve is shown in detail. If the glass breaks, the pressure of the steam drives the ball outward, filling the conical passage. When a new glass is put in, the balls are forced back by slowly screwing in the stems. This, like other safety devices, is very likely not to work when it should.

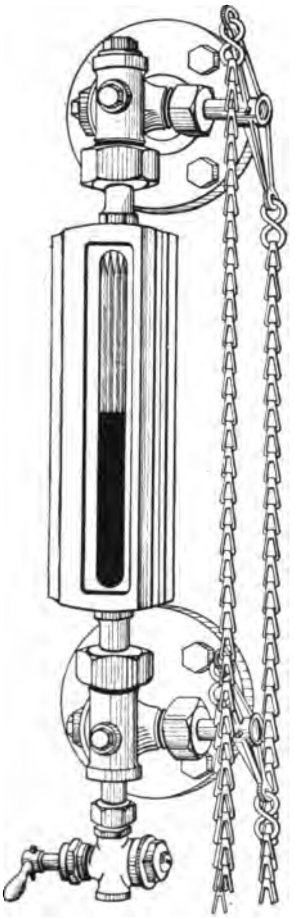

Fig. 19. Klinger Patent Gage Glass

In boilers where the steam space is small, as in locomotives, the allowable variation of water level is slight; but the greater care with which the glass is watched makes up for the small margin of safety. If dirty water is used, or if the water foams, the level in the glass will be unsteady and unreliable, since dirt clogs the passages unless they are large, and the foaming causes a fluctuation of the water level. A small pipe connecting with the steam space where no ebullition occurs will insure a steadier water level.

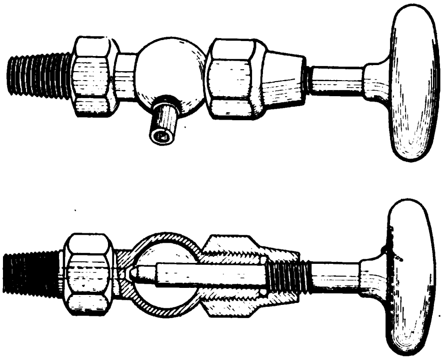

Fig. 20. Ordinary Form of Try Cock for Determining Water Level in Boiler

The chief objection to the gage glass—namely, its breaking — may be overcome to some extent by attaching it to a gage column, which is usually made of brass and stands quite clear of the boiler itself. In such an arrangement as this, the temperature in the gage glass cannot vary as widely as if it were attached directly to the boiler. The Klinger Patent water gage glass is not easily broken, and possesses many advantages over the common glass. Fig. 19 illustrates this device.

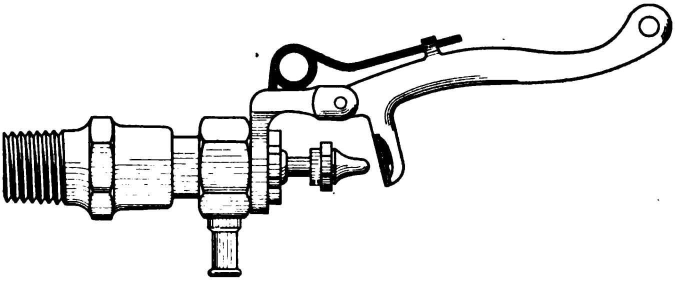

Fig. 21. Try Cock Operated by Means of Lever

Blowing Out Gage Glass. The water gage is not absolutely reliable, for the water in the gage, being cooler than that in the boiler, may not indicate the true level, and the small passages leading to it may become choked with sediment. If the gage glass is frequently blown out by the engineer and kept clean, this difficulty will be reduced.

Try Cocks. Try cocks are of widely different forms, and may be either like the general type shown in Fig. 20, which is the ordinary locomotive form, constructed in two parts so that they can be separated for the purpose of repacking without detachment from the boiler; or they may be of the lever type shown in Fig. 21. There are usually three cocks—one at the highest desired water level, one at the lowest, and one midway. More cocks may, of course, be used if desired. The water level can be determined by opening the cocks in succession and observing whether dry steam or hot water blows out. In some types of boilers the try cocks must be placed on the boiler sheets direct; in other types their use is prevented unless they are attached to a water column. Water-tube boilers enclosed in brickwork, and fire-tube boilers similarly set, would impose making the direct connections quite long, in which cases the try cocks are always attached to water columns.

VALVES

Characteristics and Uses of Cocks and Valves. Of all boiler accessories, perhaps the most important are the cocks and valves, by means of which the flow of steam or water may be shut off completely or only partly so. The valve operates by moving a disk across the pipe in a transverse direction, or by bringing a cap tight upon the seat in a fore-and-aft direction. A cock consists of a block inserted in the passageway, with an opening cut through in one direction. When the handle of the cock is in line with the pipe, the opening allows the steam to pass through; but if turned crosswise, the opening is closed.

Classification. Valves are of two kinds—those which are manually operated and those which are automatic. All control valves are manually operated, while those which are used for safety are automatic. Automatic valves may release when the pressure becomes excessive, like safety valves, or they may prevent the pressure becoming excessive by closing against steam coming from an external source, like automatic stop and check valves. Reducing valves are really one type of automatic stop and check valves, though their construction to meet the requirements of their particular service is usually somewhat different.

Application. The application of valves depends upon the severity of the service and, to a large extent, upon the opinion of the designing engineer as to the equipment as a whole. In general, the practice is growing into favor of using valves to permit the temporary removal from service of a part of the general equipment for the purpose of repairs and of employing by-passes around portions of the equipment and double service lines or loops of the same line.

MANUALLY OPERATED TYPES

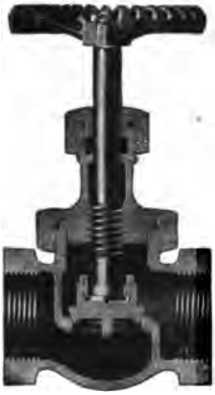

Fig. 22. Standard Globe Valve
Courtesy of Crane Company

Globe Valve. *Construction.* The valve shown in Fig. 22 gets its name from the globular shape of the casing which encloses the valve. Extending across this whole casing is a substantial diaphragm, the central portion of which is in a plane parallel with the length of the pipe. The opening is cut in this portion (horizontal in the figure) through which steam or other fluid may pass when the valve is opened. When the valve is closed, a cap is forced down to close its opening. The rim around the opening is known as the valve seat. The valve cap is operated by a spindle, which passes through the bonnet of the valve, and is mounted at the upper end by a small wheel or handle. To prevent the escape of steam around this spindle, a stuffing box is provided. The valve cap may or may not rotate as the spindle turns; usually it does not.

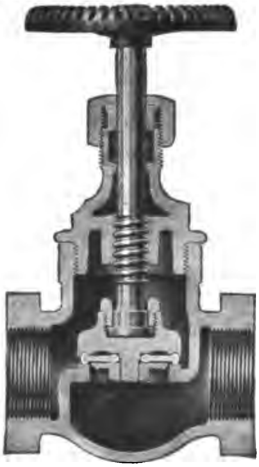

Fig. 23. Extra Heavy Copper Disk Globe Valve
Courtesy of Crane Company

Replacements. The valve shown in Fig. 22 is a standard globe valve known to the trade as the Crane Navy valve. It is a good valve of the type and is tested up to 250 pounds hydraulic pressure per square inch. If the disk or seat becomes scored, the valve may easily be reground.

A valve shown in Fig. 23 has a detachable valve cap. Instead of relying for tightness upon the valve and seat coming together, metal to metal, a removable disk is provided, which, being softer than the metal valve seat, easily takes up the wear, and the valve not only can be closed tighter but, if anything happens to impair the tightness of the valve, the copper disk can be replaced by another at a trifling expense. In cheaper valves, when the cap is scored, the valve is worthless. The valve seat sometimes has a slight bevel, as in Fig. 22, the valve cap being shaped like the frustrum of a cone.

It is impossible to close a valve tightly if the slightest particle of scale or grit gets between the disk and the seat. If this happens, the valve seat is likely to become scored, and so does not hold tight; but it may be reground and, if the valve disk itself is damaged, can readily be replaced.

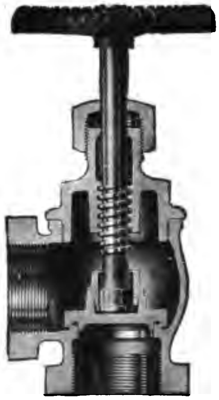

Fig. 24. Angle Valve
Courtesy of Crane Company

Angle Valve. An angle valve, shown in Fig. 24, is similar in construction to the ordinary globe valve, and is sometimes used in place of the straightway valve and an elbow. Both these styles of valve should be so placed in the steam pipe that the entering steam comes beneath the valve seat. If this is done, the valve stem may be easily repacked simply by closing the valve. If the steam enters in the opposite direction, a leaky valve stem cannot be packed, as loosening the stuffing box would permit the escape of the steam. There are, however, exceptions to this rule.

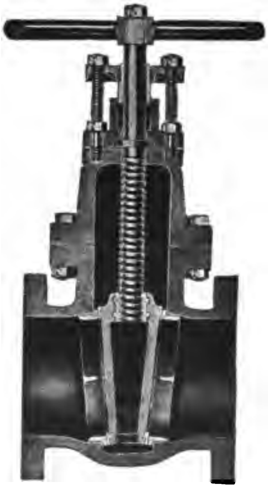

Fig. 25. Crane Wedge Gate Valve, with Non-Rising Stem
Courtesy of Crane Company

Gate Valve. The gate or straightway valve gives a straight passage through the pipe, and, when open, offers very little resistance to flow. The globe valve, of course, offers much resistance, because the fluid has to change its direction of flow completely.

There are two forms of gate valve—one with wedge-shaped sides, and the other having the valve sides parallel. Fig. 25 shows a Crane valve with wedge-shaped sides. A collar holds the valve spindle at a fixed point, and to open or close, the valve is drawn up or lowered by turning the spindle. When the gate reaches the bottom of the pipe, a wedge on the lower end of the spindle causes the sides to move laterally with sufficient force to bring a strong pressure against the valve seat. For heavy work these valves are made with a rising spindle instead of a stationary one. This possesses the distinct advantage of indicating at a glance whether they are opened or closed, while one cannot tell by looking at the ordinary gate valve whether it is open or not.

Check Valve. When it is necessary that the flow should always take place in the same direction, as in the feed pipe of a boiler, check valves are used. There are several forms shown in Fig. 26, one of which is of a pattern similar to a globe valve. This check valve is of a ball or flat type, the seat being parallel to the direction of flow. The valve is held in place by its own weight, and by the pressure of the fluid in case of a reverse flow. In the swinging check valve, the seat is at an angle of about 45 degrees to the direction of flow. It is fitted somewhat loosely where it is fastened to the swinging arm, so that it may properly seat itself. This form is usually preferred, as it offers less resistance to flow, and there is less chance for impurities to lodge on the valve seat. When a check valve is used in the boiler feed pipe, there should be a stop valve between it and the boiler which can be shut in case the check valve should get out of order.

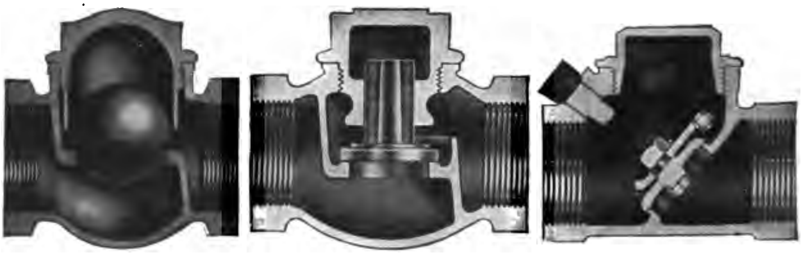

Fig. 26. Horizontal Check Valves. Left, Ball Type; Middle, Cup Type with Flat Seat; Right, Swinging Type

Materials Used in Construction. For pressures under 200 pounds per square inch, cast iron may be used for the body of the valve; but, for economy, it should be used only when the pressure is over 130 pounds. For heavy work it is frequently necessary to have a massive valve that cannot be broken easily. In such a case a cast-iron body is the most suitable thing. The valve seat, valves, spindles, stuffing box, glands, and nuts are usually made of gun metal or brass. For very high pressures, especially on steam mains, cast steel is generally used, with gun metal fittings similar to those enumerated for the cast-iron valves.

AUTOMATICALLY OPERATED VALVES

Safety Valves. Safety valves are used for relieving the boiler when the pressure exceeds a certain limit, and to give warning of high pressure. There are several different types, but the essential feature is a valve opening upward, held on its seat by a weight or spring. When the pressure in the boiler exerts a force greater than that holding down the valve, the valve will open automatically.

Lever Safety Valve. The lever safety valve shown in Fig. 27 is a common type for stationary work, especially for small boilers.

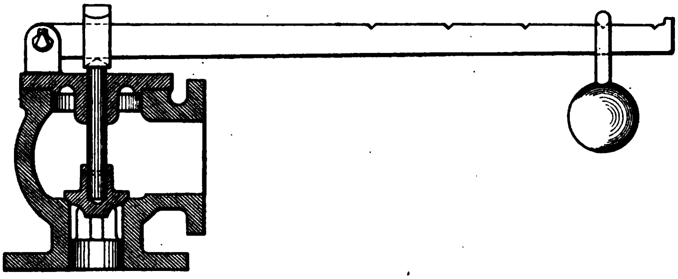

Fig. 27. Common Type of Lever Safety Valve

The valve is held in place by a weight at the end of a lever. The force required to lift the valve is governed by the location of the weight on the lever arm. The body of the valve is usually made of cast iron, the seat being of brass. An opening on the side of the valve may be connected with the feed-water heater or drain, if the escape of steam into the air is undesirable. If the valve becomes leaky, it should be reground; but no attempt should be made to make it tight by increasing or moving the weight on the lever.

The amount of necessary weight on the lever, and its distance from the fulcrum, can be determined in the usual manner of computing leverage forces and moments, remembering that weight times weight arm is equal to power times power arm. In such a valve as this, power is the steam pressure, and the power arm is the distance of the center of the valve from the fulcrum. There are four weights acting downward—the ball, the lever arm, the valve, and the spindle—and in the process of computation the weight and leverage of each must be taken into account.

Suppose, for example, that we have a lever safety valve such as is illustrated in outline in Fig. 28, and that we know the following conditions: the ball weighs 125 lbs., and is suspended at the end of the lever 48 inches from the fulcrum; the valve and valve spindle together weigh 18 lbs., and are 4½ inches from the fulcrum; the lever arm itself weighs 50 lbs. If the valve seat is 5 inches in diameter, at what pressure will the valve blow off, ignoring the friction of the stuffing box and fulcrum pivot?

The center of gravity of the lever arm must be determined from the drawing, Fig. 28, and this is found to be 20 inches from the fulcrum. The leverage of the weights acting downward is then as follows:

Ball................ $125\times 48 = 6{,}000$
Lever............... $50\times 20 = 1{,}000$
Valve and Stem...... $18\times 4\frac{1}{2} = \underline{\quad 81}$
Total moment........... $= 7{,}081$ inch-pounds

Now, if the valve-seat diameter is 5 inches, the area of the valve will be

$$\frac{\pi D^2}{4} = \frac{3.1416\times 25}{4} = 19.63 \text{ sq. in.}$$

The total moment to be overcome is 7,081 inch-pounds, and its distance from the fulcrum is 4½ inches. Therefore, the necessary upward pressure on the valve will be $\frac{7{,}081}{4\frac{1}{2}}$ or 1,573.5 pounds. If the area of the valve is 19.63 square inches, then the necessary pressure in pounds per square inch would be $\frac{1{,}573.5}{19.63}$ or 80 pounds,

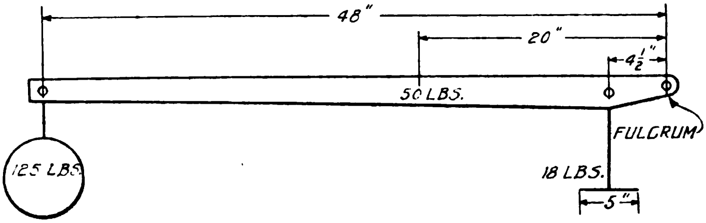

Fig. 28. Diagram for Safety-Valve Calculations

approximately. That is, this safety valve would blow off when the boiler pressure reached 80 pounds per square inch.

If it is desired to design a valve which will blow off at known pressure, the same principles will apply, but the computations will be figured in the reverse order. The area of the valve, times the boiler pressure, would give the total lifting force; and this, multiplied by its leverage, would give the lifting moment, which would be resisted by the downward moment of the combined weights of valve, valve stem, lever, and ball. If the moments of the lever, valve, and valve stem were known, the remainder, of course, would be made up by the ball. If the length of the lever arm were known, then the weight of the ball would be varied to correspond; and, conversely, if the weight of the ball were fixed, the length of the lever must be made to correspond.

The lever safety valve has several defects. It does not close promptly when the pressure is reduced; and it is likely to leak after it is closed, and may be readily overloaded, or even wedged on its seat. It is essential that a safety valve should be automatic, certain in its action, and prompt in opening and closing at the required pressures. It must be one which can be relied upon under all circumstances and not easily tampered with.

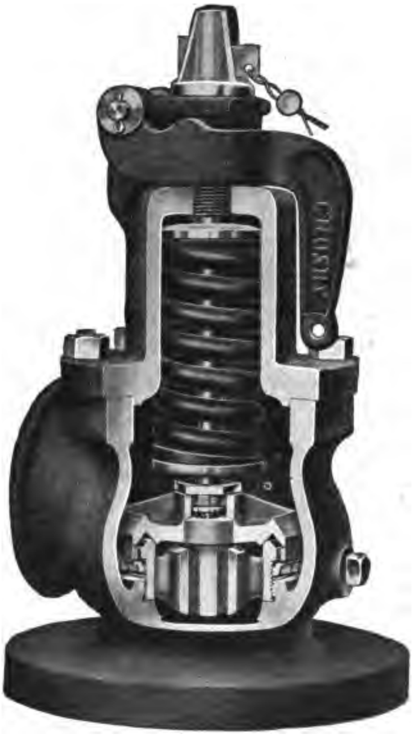

Fig. 29. Crosby Pop Safety Valve for Stationary Boilers

Pop Safety Valve. The pop safety valve fulfills the above requirements better than those of the lever type. Pop valves open when the steam pressure is sufficient to overcome the tension of the spring. Fig. 29 shows a Crosby pop safety valve for stationary service. The valve is connected by a flange to the central spindle and is held down on its seat by the pressure of the central spring. The valve is provided with wing guides and an annular lip. The guides fit smoothly into the seating upon which the valve rests. The seats of the valve have an angle of 45 degrees. The under face of the lip, together with the seating, forms a small chamber through which all the steam must pass in order to reach the open air.

The valve shown in Fig. 30 for stationary boilers is made by the Ashton Valve Company. The general principles are those of all pop safety valves. The valve seat is made of composition or nickel, and with a bevel of 45 degrees, as is the United States Government standard. The pop chamber is surrounded by a knife-edge lip, which wears down in proportion with the seat, thus keeping the outlet of the same relative proportions and giving a constant amount of pop.

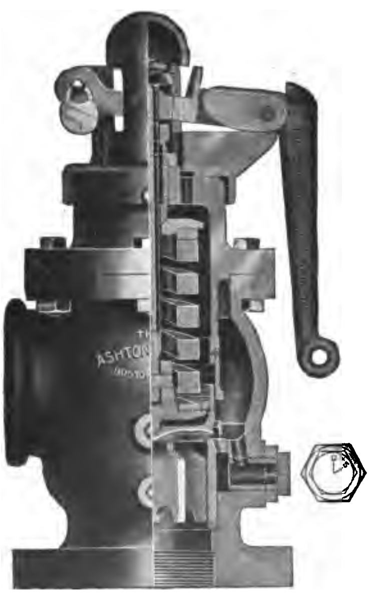

Fig. 30. Improved Lock-Up Pop Safety Valve

The amount of pop—that is, the difference of pressure between the opening and the closing of the valve—is regulated from the outside by means of the screw-plug pop regulator shown in section and plan at the lower right hand of Fig. 30. If more pop is desired, turn the regulator so that *S* will be more nearly perpendicular. To lessen pop, make *O* more nearly perpendicular. The springs are made of Jessop's best steel and are held by pivoted disks at the top and bottom to insure a true bearing on the valve.

The inlet and outlet are both on the same casting, so that the valve may be taken apart to be cleaned or repaired without disturbing the boiler connection. It has a lock-up attachment, so that the regulating parts cannot be tampered with, either by accident or by design. The spring is encased, in order to protect it from the steam.

The Crane Marine pop safety valve is shown in Fig. 31. It has a bevel seat, and is provided with a cam lever, by which it may be raised from its seat one-eighth of the valve opening. The lever can be thrown over far enough to lock the valve open when there is no steam pressure. The outlet of the valve, if desired, may be piped to the supply tank or to any other point.

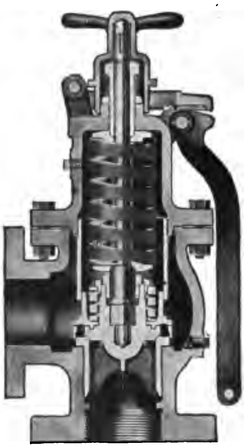

Fig. 31. Crane Marine Pop Safety Valve

Locomotive Safety Valves. Safety valves for locomotive boilers must be made of heavy material to stand the severe usage. They should be so constructed that they will not cock or tilt. The Ashton valve shown in Fig. 32 is constructed so that the amount of pop can be regulated by merely turning the two posts marked *2* and *3* to the right or left. The noise of the steam escaping from the ordinary safety valve is disagreeable, and in some States the law requires the use of the muffler safety valve. The Ashton valve shown in Fig. 32 has a top muffler.

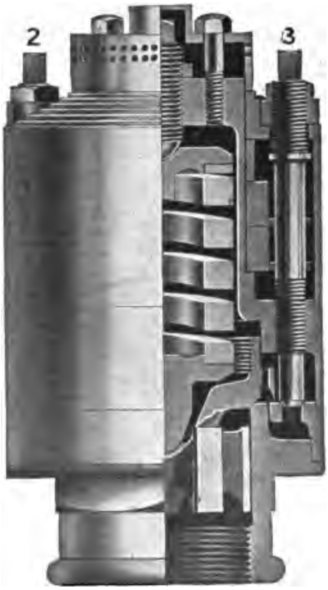

Fig 32. Ashton Locomotive Increased-Lift Muffled Pop Safety Valve

Safety valves should be connected directly to the boiler without any pipe or elbow. They should be tried every day by means of the lever. It is best not to locate safety valves on the steam outlet main leading from the boiler.

Blow-Off Cocks. It is customary and good practice to locate between the boiler and the blow-off valve a cock known as the blow-off cock, which answers the purpose of carrying the boiler pressure and receiving the worst service of scale and muddy sediment at times when the boiler under pressure is being blown down. Simplicity of construction and tightness are the main requirements sought. Fig. 33 illustrates the Homestead blow-off cock.

This valve is so constructed that when it is closed it is at the same time forced firmly to its seat. This result is secured by means of the traveling cam *A*, through which the stem passes. The cam is prevented from turning with the stem by means of the lugs *B*, which move vertically in slots. Supposing the valve to be open, the cam will be in the lower part of the chamber in which it is placed, and the plug will be free to be easily moved. A quarter of a turn in the direction for closing it causes the cam to rise and take a bearing on the upper surface of the chamber, and the only effect of further effort to turn the stem in that direction is to force the plug more firmly to its seat. A slight motion in the other direction immediately releases the cam, and the plug turns easily, being arrested at its proper open position by contact of the fingers of the cam at the other end of its travel. *E* and *D* are balancing ports.

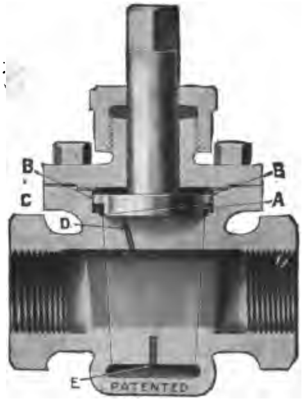

Fig. 33. Blow-Off Cock
Courtesy of Homestead Valve Manufacturing Company

Blow-Off Valves. The severity of the service mentioned in a preceding paragraph which all blow-off valves have to withstand, owing to the cutting action of scale and other gritty sediment, has caused designing engineers to pay particular attention to these valves. Many forms have been devised which, while they are bound to have the essential features of globe, angle, straightway, or Y valves, are so constructed that the danger of scoring the valve disks or seats is materially reduced.

Fig. 34 illustrates a straightway blow-off valve known as the Everlasting. It consists of a top and bottom bonnet, a disk, and a lever and post. To open, the disk is simply drawn away from its seat to one side by moving the lever arm. The Faber blow-off valve is shown in Fig. 35. One feature of this valve is a separate half-inch pipe line connected with the boiler above the mud drum or to the steam main joined to the valve at *C*. It will be seen that the seat of the valve is still in communication with steam or water at boiler pressure even after the valve disk is about to close on its seat; this steam, as it blows over the valve seat and disk, is intended to cleanse both. This half-inch line, while it contains a valve, should always be open during normal operation.

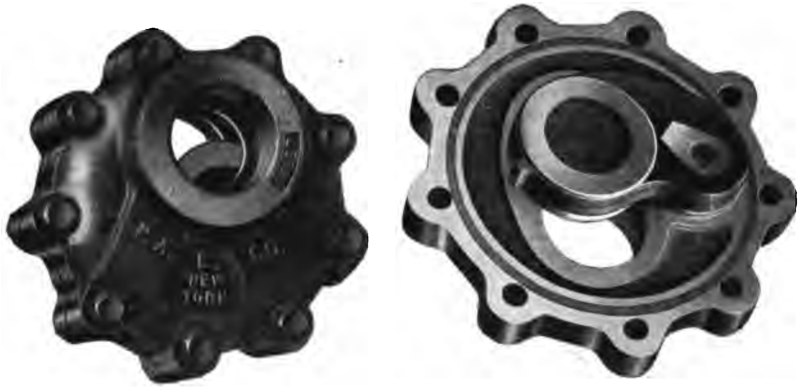

Fig. 34. Views of Everlasting Blow-Off Valve
Courtesy of Scully Steel and Iron Company

Automatic Stop and Check Valves. Where several boilers in service are attached to the same steam main, there is the possibility that a failure on the part of one of the boilers will relieve the steam pressure in the steam main very quickly unless provision is made automatically to cut the boiler affected out of service from the remainder of the boilers. To meet this service, a type of valve has been developed known as the automatic stop and check valve. It is located immediately adjacent to the boiler as close to the steam space as possible, with no valves intervening, separate and distinct from the control valve of the boiler, which is located adjacent to it or as close as may be.

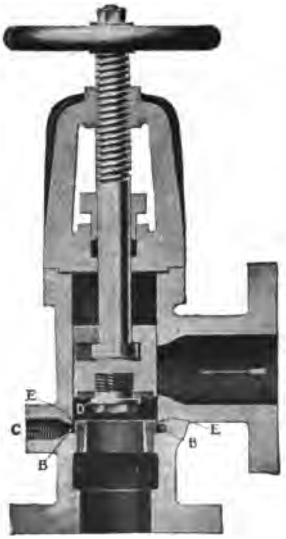

Fig. 35. Faber Blow-Off Valve
Courtesy of Elliott Company

It will be readily understood that, should a boiler fail so as to let its steam and water out quickly, and should this boiler be equipped with a valve of the kind mentioned, the remainder of the boilers could go on with their work without disturbance, while, without such provision, the steam coming from the unaffected boilers would flow to the affected one and pass through its rupture. Many municipalities and States require the use of automatic stop and check valves when more than one boiler is attached to one main, and the practice is gradually becoming universal. The valve shown in Fig. 36 is one of a great many intended for use in such places as mentioned, and is made by the Golden-Anderson Valve Specialty Company. An inspection of the illustration shows that, while the stem can be turned down to close the valve should it be open, it cannot raise the valve disk from its seat should it be closed, there being no fastening between the stem and the disk. The requirement that a valve of this character must be unerring in its service demands the best material and workmanship.

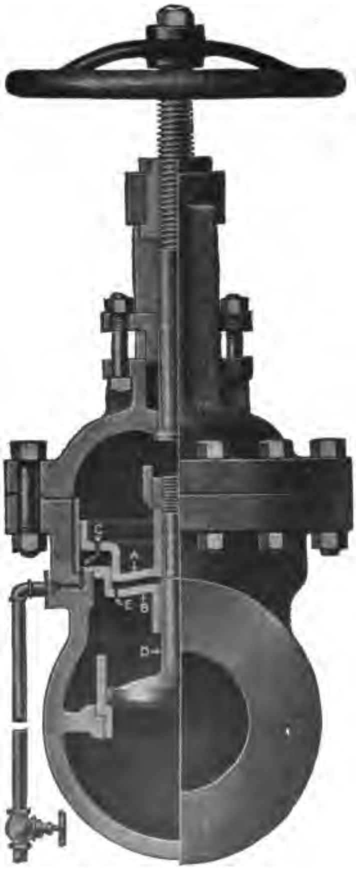

Fig. 36. Golden-Anderson Double-Cushioned Non-Return Valve

Reducing Valves. Sometimes steam is desired at a lower pressure than that of the boiler. For instance, a small low-pressure engine may be run by steam taken from the same boiler that supplies a higher-pressure engine. This reduction is accomplished by throttling the steam by means of reducing valves. These are arranged to be operated automatically, so that the pressure can be reduced and a constant pressure in the steam pipes maintained. There are several forms in general use.

In the Holt valve, Fig. 37, the low-pressure steam acts on the lower side of the diaphragm; and the weight, which may be set so as to cause the desired pressure, acts on the other. The movement of this diaphragm causes a balanced valve to move to or from its seat. The valve opens until the steam pressure equals the weight above. The pressure in the main steam pipe does not affect the movement of the valve. It depends only upon the pressure on the two sides of the diaphragm.

In the Mason valve, Fig. 38, a spring, which may have its tension altered by a key, takes the place of the lever and weight in the Holt valve. When the pressure in the low-pressure system has risen to the required point, which is determined by the spring, the valve closes, and no more steam is admitted until the pressure falls sufficiently to open the valve again.

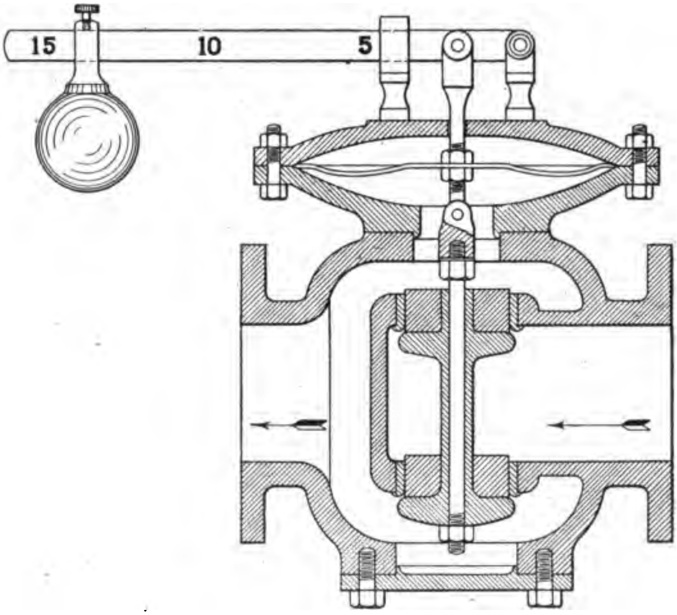

Fig. 37. Holt Reducing Valve with Diaphragm Regulating Pressure

In another form of valve, a piston acted on by the low-pressure steam regulates the opening of a balanced valve, and this maintains a constant steam pressure.

In the Foster reducing valve, the valve is held open by the spring and levers, until the steam pressure at exit presses on the diaphragm sufficiently to close the valve. The valve is held open so as to admit just the proper amount of steam to maintain the required pressure.

When a reducing valve is used, a stop valve should be put in to prevent flow when steam is not in use.

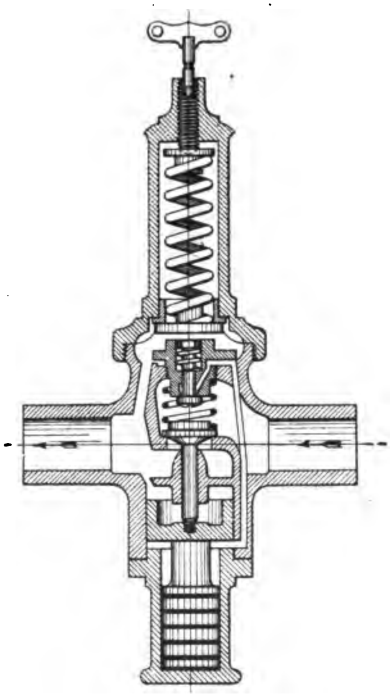

Fig. 38. Mason Reducing Valve. Pressure Regulated by Means of a Spring

STEAM PIPING

The subject of steam piping in its entirety is one far beyond the scope of this treatment of boiler accessories, but it is essential that it be brought up to the extent of emphasizing its importance, especially as concerns the steam connections from the boilers to the main steam header.

Precautions. *Provide for Drainage.* The first requirement is that all piping must be so arranged that the condensation can be drained. A failure to provide drains may be responsible for the rupture of engines and any other apparatus located in line with the engine. For the same reason, it is customary to locate control valves in the high parts of steam pipes connecting boilers and steam mains so that the condensation may flow freely in either direction.

Flexible Connections. As a second requirement, ample provision should be made for flexible steam pipe connections to the main header. This is accomplished by the use of long sweep bends. It is especially important that attention be paid to the flexibility of the blow-off connections, as the distance between the blow-off openings and the blow-off main is usually short. If the connections are rigid, a stress is thrown upon the flange connecting the blow-off pipe to the boiler, resulting in a leaky joint. It is well to remember that the blow-off main is subjected to wide ranges of temperature which cause a corresponding deformation in length, which is distributed among the various branches and attachments.

Proper Strength of Pipe and Allowance for Expansion. Pipes must not only be of sufficient size and strength, but should be so installed as to make ample provision for expansion due to the high temperature when they are filled with steam. The supports for long pipe lines should be arranged somewhat as shown in Fig. 39, which allows the pipe a considerable amount of lateral motion.

Expansion Joint in Long Pipes. If the pipe line is long, an expansion joint must be provided. Sometimes a curved U-bend may be inserted in the pipe line, which of itself will have flexibility enough to provide for reasonable expansion. Or, if the steam main is not all in one line, a similar bend may be provided, with elbows and nipples, Fig. 40. In this case, any expansion of the steam main will cause the nipples to turn slightly in the elbows. This motion, of course, is slight, but it is sufficient to prevent rupture. For large pipes a slip joint, made tight by a stuffing gland, is usually provided. If this is done, great care must be taken that the steam main is straight and in perfect alignment, as the pipe may otherwise bind in the expansion joint and cause much damage from leakage.

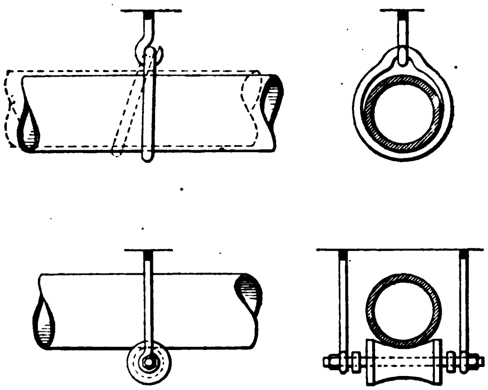

Fig. 39. Side and Transverse Sectional Views Showing Methods of Arranging Supports for Long Pipe Lines

Straight and Sloping Runs to Avoid Condensation. In marine work, especial care must be taken that the pipe lines are not so rigidly connected together that they will be injured by the working of the ship. This can be readily provided for by laying the pipe in such a way as to provide a simple form of swivel joint.

The pipe lines should be as straight as possible, to prevent unnecessary friction of the steam and unnecessary condensation; and they should, if possible, be so installed as to leave no pockets wherein condensation may collect. If such a pocket is unavoidable, a drain must be provided, leading from the pocket to the steam trap, whence the condensation may be discharged into the hot well or filter box, because the collection of water in steam pipes is a source of inconvenience and danger.

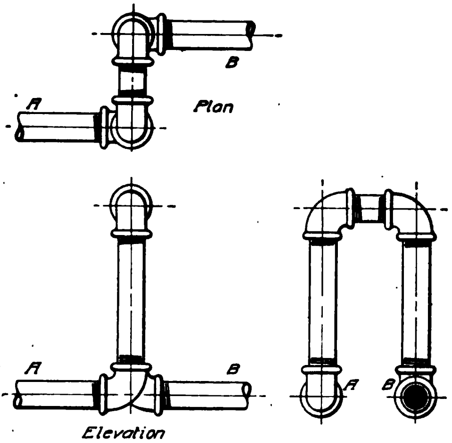

Fig. 40. Method of Forming Swivel Joint in Steam Piping to Counteract Effects of Expansion and Contraction

The pipe lines should be installed with sufficient slope, so that the condensation will readily drain to a convenient point, whence it may be drawn off. This slope should be in the direction of the flow of the steam, as the water will not readily flow otherwise. Great care should be taken that the pipe lines nowhere sag, as such a depression will collect condensation. This may cause very little disturbance unless the pressure of the steam is suddenly raised, in which case the water is likely to flow bodily along the pipe; and if it does not enter the cylinder of the engine and cause damage there, it will cause a serious water hammer, which may rupture the elbows of the pipe and endanger life.

Materials for Piping. Formerly, when low pressures were used, cast iron was a common material for a main steam pipe leading from the boiler to the engine, but the higher pressures of today require the best wrought iron or steel. In marine work, copper is commonly used; but with the advent of higher and higher pressures, copper fails to give the requisite strength, and it has to be reinforced with wire or iron bands. According to the British Board of Trade Rules copper pipes 15 inches in diameter may be used at pressures not over 150 pounds; but at 200 pounds, copper pipes over 10 inches in diameter are not allowed as there is always danger that the large copper pipe will burst. For large sizes, riveted iron or steel pipe may be used. For high pressures, cast-steel fittings are required by the U. S. Steamboat Inspection rules. It is now the common practice to use steel for such purposes.

Pipe Connections. *Gasketed Joints.* Large steam pipe is made in sections which can be riveted together. The small sizes are fitted with the ordinary type of flange, and the sections may be bolted together, a suitable gasket being used between the two flanges to make a steam-tight joint. The flanges are machined perfectly smooth, and the packing may consist of rubber and fiber reinforced with wire insertion; of asbestos; or of corrugated copper.

Flanges and Unions. As the pressures used have become higher it has been necessary to construct tighter and stronger connections in both steam and water mains attached to boilers. This is especially true since the use of superheated steam has become general. Only a few of the methods in use can be brought up here. Fig. 41 shows the Edward flange, which is intended to avoid the use of gaskets between the two adjacent flanges. To accomplish this, the annular V-shaped projection shown in the upper flange is inserted into the companion groove of the lower, both being drawn together by bolts. The narrow slot in the edge of the upper V serves to insure a tighter joint. An application of the same principle in the making of a box union is shown in Fig. 42.

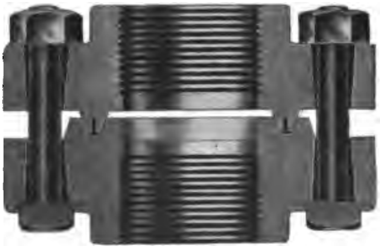

Fig. 41. Edward Flanged Union
Courtesy of Edward Steam Specialty Company

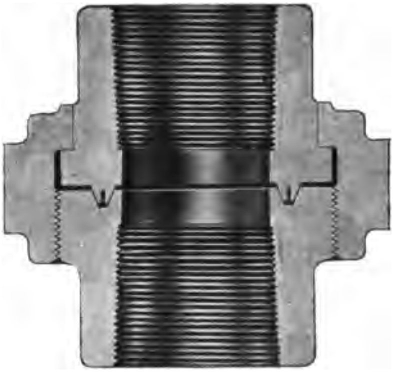

Fig. 42. Edward Box Union

Pipe Sizes. The true inside diameter of steam, gas, or water pipe is not always the same as the size by which the pipe is designated. For instance, what is called "3-inch" pipe has an actual inside diameter of 3.067 inches, and 3.5 inches outside diameter. The actual sizes of pipe, inside and outside, are to be found in any handbook or steamfitter's catalogue.

WATER END AUXILIARIES

FEED WATER REQUIREMENTS

Adequate Provisions Important. Perhaps the most important of all auxiliaries connected with a boiler is its feed apparatus. This is vital; for, if the feed is interrupted and the water runs low in the boiler, not only is there danger of damaging the boiler itself, but a disaster may follow of far greater concern. For marine purposes—and the same is true to a considerable extent in stationary work—at least two independent feed systems should be provided. In marine work, the main feed pump draws water from the filter box or feed-water heater, and pumps it into the boilers under ordinary conditions. There should be a by-pass around this pump, and the feed line should be connected by means of a valve to what is known as the "donkey" pump, which may be used for auxiliary feed purposes in case the main pump is damaged or in need of repairs.

Both of these pumps draw from and discharge into the same feed line; but, to provide against emergencies, there is usually a cross connection to the sea, so that sea water may be had if necessary. While in port, when the main engines are not running, and consequently when the feed water cannot be heated economically, an injector is almost invariably used. On land it is usually considered sufficient to install an injector in addition to the feed pump, although in large plants an auxiliary feed pump should be installed as well. In a small plant the fireman usually attends to the water; but on board ship and in large plants, a water tender is usually provided, whose business it is to keep the water in the boiler at the proper level. His task may be materially lessened by some automatic arrangement, so that if the water discharged into the hot well from the condenser rises above the normal level, a float will open the valve leading to the feed pump and increase the rapidity of its stroke. This will reduce the level of the hot well or filter box, as the case may be.

Such an arrangement as this will keep a fairly uniform level of water in the boilers; and if a surface condenser is employed, and all the condensation is pumped back into the boilers, the water level will remain constant except for slight leakages of steam, and for the possibility of improper action of the feed pump. Leakage of steam can be made up from the supply of fresh water. At sea, salt water may have to be used for this purpose, although its use is very objectionable.

Location of Feed-Water Connection. There is considerable difference of opinion as to where the feed water should be introduced into the boiler, although the consensus of opinion seems to be that it should enter not far from the water line. In stationary practice, where the marine type of boiler is used, the feed water is introduced at the rear of the boiler near the bottom; but this is open to grave objections, for the feed water, being comparatively cool, and being introduced into the coldest part of the boiler, naturally tends to become dead water and to retard proper circulation, which is essential to economical steaming and often essential to the safety of the boiler itself.

Location Depends Upon Type of Boiler. The best place for introducing the feed water will naturally depend upon the type of boiler, and the service for which it is intended. If the entering water is of high temperature, it might enter near the bottom of the boiler. But if the feed water is comparatively cold—and it is always colder than the water in the boiler and the surrounding steam if the circulation is good—great care must be taken that it does not strike directly against the hot boiler plates, as it might thereby cause local contraction and possibly a serious leak, and it should be introduced in such a way as to make sure of its aiding the natural circulation of the boiler.

Practice in High-Pressure Work. The higher the steam pressure in the boiler, the more difficult becomes the problem of feed, and the more danger there is of injury to the boiler by the comparatively cold feed water striking hot plates. It is a universal practice in marine work, and a common practice on land, especially for internally-fired boilers, to cause the feed to enter above the water level near the center of the boiler; then branching off into two pipes, one leading to each side through the steam space until the side of the boiler is reached; and then running downward toward the bottom. The feed water, which very likely has been previously heated by a feed-water heater, is still further heated by its passage through this feed pipe, which is in direct contact with the live steam of the boiler. This internal feed pipe, turning down at the sides, causes the water to strike the outer shell of the boiler, which is the most remote from the fire, and this downward motion materially assists the circulation in the boiler. When this arrangement of feed is adopted, Fig. 43, care must be taken that the lower end of the feed pipe is well below the low-water level. If the end of the pipe is alternately immersed in water and then exposed to steam, violent explosions in the pipe are likely to follow, although nothing more serious may result than breaking an elbow or frightening the attendants.

Practice in Stationary Work. In stationary practice, it is quite common to admit the feed water into the steam space through a horizontal pipe which enters this space through the tube plate a few inches below the low-water level and terminates in a perforated pipe of large diameter. This method distributes the feed water admirably, and allows it to become considerably heated before it reaches the bottom of the boiler. If the feed water contains a considerable amount of magnesia or calcium carbonate, holes so arranged in the feed pipe are likely to become clogged and the feed consequently interrupted. Water of this sort should be fed into a trough, or the feed pipe be opened at the top by a long slot, so that the feed water may overflow. The trough, in this case, forms an admirable mud drum or sediment collector.

Practice with Internally-Fired Boilers. In internally-fired boilers of the Cornish or Lancashire types, the feed is usually delivered near the bottom through a horizontal pipe—either through the

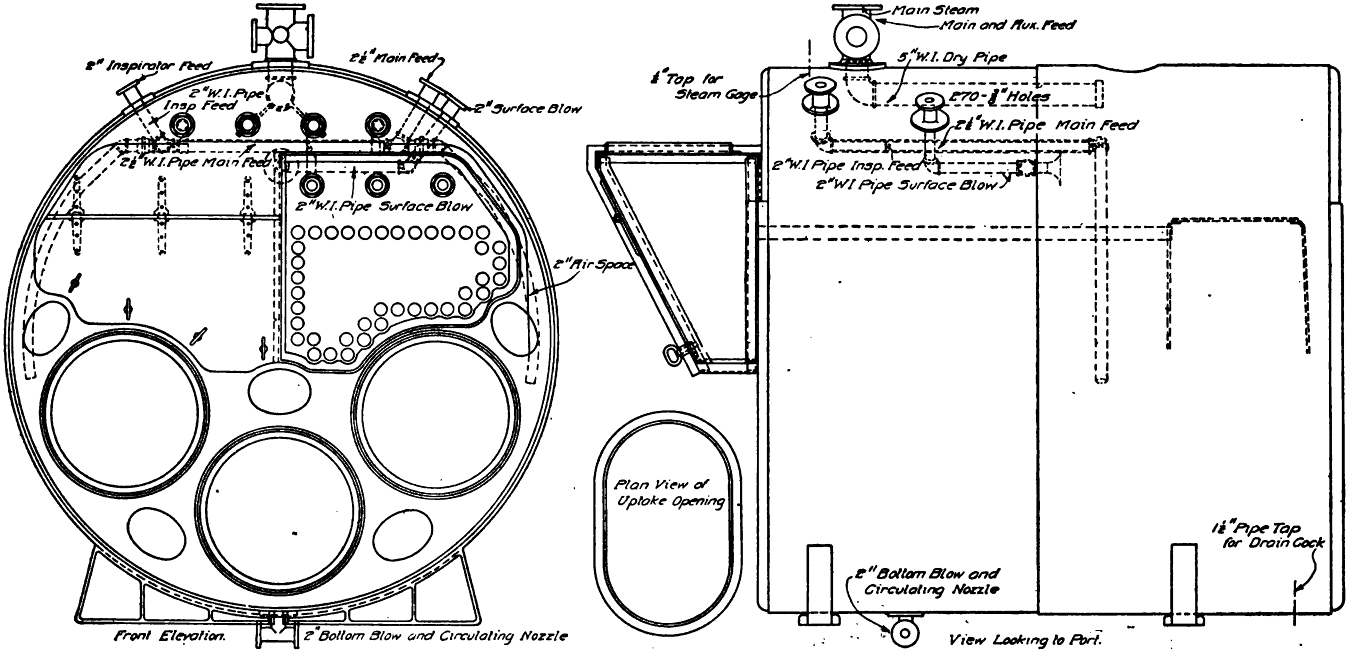

Fig. 43. Scotch Boiler of Marine Type Showing Arrangement of Surface and Bottom Blow-Outs, and Internal-Feed Piping

front end or by a vertical pipe through the crown. This method is not conducive to the best circulation.

In addition to these effects on circulation, there are other grave objections to introducing feed water near the bottom of the boiler; for, should anything happen to the feed pump, or a piece of scale lodge under the check valve, the water might be almost entirely blown out of the boiler before the difficulty could be discovered or remedied. If the pipe enters in the vicinity of the low-water level, no water could be drawn out below this point.

Use of Spray. Sometimes the feed water is forced into the steam space in the form of a fine spray. In this way it not only is thoroughly heated before mingling with the water in the boiler, but the air is taken out, and salts, such as sulphate of lime, insoluble at high temperatures, are immediately precipitated; but the advantage of introducing the feed water in a body, so as to produce useful circulating currents, should not be overlooked.

Constant Level of Water Desirable. Under ordinary circumstances the feed supply should be regulated so as to keep the water level as nearly uniform as possible. This statement requires modification to the extent that it is desirable to permit stored water to be reduced in height to meet a sudden increase of load until the firing conditions can equal or slightly exceed the immediate requirements for steam. The reverse is true when there is a reduction of the steam required, in which case it is permissible to allow the water to rise above a normal point ready for an increased load.

Practice with Water-Tube Boilers. The development of the water-tube boiler has brought about several modifications in the feeding systems internal to the boiler as compared with the large shell boilers. The circulation of water within them being more positive makes it easier to locate proper outlets, though the scheme of forcing the water to remain inside of internal piping until it has risen in temperature is preserved. Under no circumstances is the water introduced immediately before reaching the most effective heating surface. In some instances manufacturers introduce enlarged internal pipe structures within the upper drums with the intention of precipitating the low temperature precipitates, expecting to blow these out without allowing them to enter the general circulation of the boiler.

Separate Feed Control with Boiler Battery. If several boilers are attached together in the form of a battery, each boiler should be supplied with an independent connection to the feed pipe, otherwise a damage to the feed pipe in one boiler might affect the others. Moreover, if several boilers are fed from one pipe, the pressure in each of them being slightly different, an excess of water will naturally be fed into the boiler having the least pressure, whereas it is usually the case that the most water is needed in the boiler having the greatest pressure. The foregoing is equivalent to saying that each boiler should have its own feed-control valve. Where one boiler unit has several drums, one feed-control valve in one line may serve all of the drums, but the best practice requires that each drum shall have its own branch feed. Each branch feed should also have a check valve and a control valve, or a combination of a check and control valve.

Internal Piping. Internal piping should be substantial and so constructed that it is either easily taken apart for cleaning or easily cleaned while in place. This piping is preferably made of brass, and some boiler laws make this a requirement.

PUMPS

Reciprocating Pumps. *Characteristics.* Boilers are usually fed by a small, direct-acting steam pump placed near the boiler. Although these pumps require a large steam supply per horsepower per hour, the total amount of steam used is small because the work done is small. If a feed-water heater which can use the exhaust from the pump is used, the disadvantage of uneconomical steam use in a reciprocating feed pump disappears. A more economical pump is a power pump driven by a large steam engine; but in this case the rate at which water is supplied is not easily regulated to the demand of the boiler. Power pumps are usually arranged to pump a larger quantity of water into the boiler than is required, the excess of water being allowed to flow back into the suction pipe through a relief valve.

Method of Action. The Worthington duplex pump shown in Fig. 44 is well adapted for feeding boilers. In Fig. 45 is shown a section of the same pump. Steam, controlled by valves, drives the

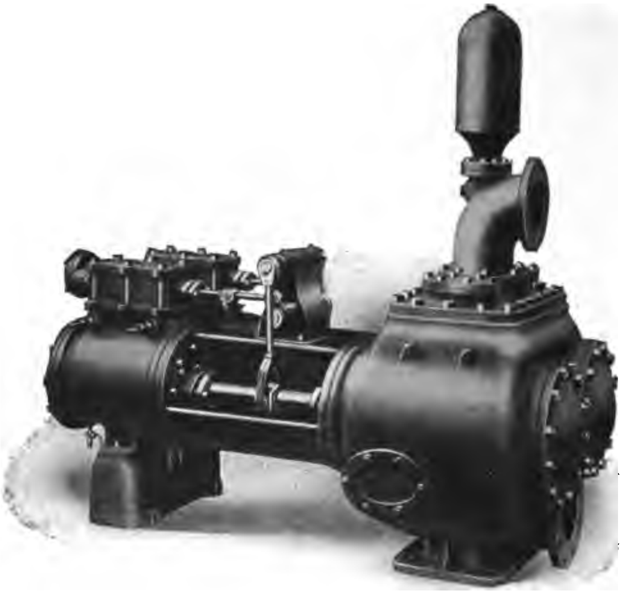

Fig. 44. Straightway Piston Pattern Duplex Pump
Courtesy of Henry R. Worthington, New York City

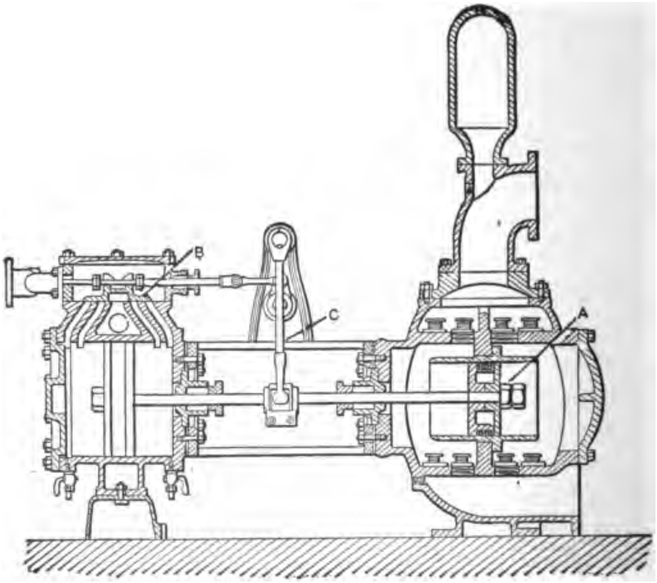

Fig. 45. Section of Worthington Duplex Pump

piston in the steam cylinder, which moves the plunger in the water cylinder, since both are fastened to the same rod. The movement of the plunger forces a part of the water in front of it up through the valves into the air chamber, and through the pipes into the boiler. On account of the partial vacuum caused by the movement of the plunger, water will be drawn from the suction pipe, through the valves, into the pump cylinder, filling the space left by the movement of the plunger. During the return stroke, this water is forced up into the air chamber, and a like quantity enters the other end of the pump cylinder. The valves are kept on the seats by light springs, until the pressure on the bottom side is sufficient to lift them and allow water to flow through.

When two pumps are placed side by side, and have a common delivery pipe, the machine is called a duplex pump. It is usual to set the steam valves so that when one piston is at the end, the other is at the middle of its stroke. A duplex pump having a large air chamber and valves set to act in this manner delivers water with an approximately constant velocity.

Injectors. *Energy of the Jet.* Water may be forced into a boiler by an injector, or inspirator. By means of this instrument, the energy of a jet of steam is used to force the water into the boiler. That there is sufficient energy to do this work is evident from the fact that each pound of steam, in condensing, gives up about 1,000 B. t. u., and a B. t. u. is equivalent to 778 foot-pounds. Not all the energy of the jet of steam is used in forcing water into the boiler; some is wasted, and much is used to heat the feed water.

Method of Action. The action of the injector is briefly as follows: The steam escapes from the boiler with great velocity and, as it passes through the cone-shaped passage, draws air along with it, thus creating a partial vacuum in the suction pipe. Atmospheric pressure forces water up into the suction pipe, and the jet of steam which it meets is partly condensed. The energy of the jet carries the water along with it into the boiler.

Experiments show that the injector, if considered as a pump, has a very low efficiency. When used for feeding a boiler, it has a thermal efficiency of nearly 100 per cent, since all the heat of the steam passes to the water except the slight amount lost in radiation. The pump, however, has one great advantage over the injector. It can force hot water from a heater into the boiler, while an injector can be used only with cold or moderately warm water.

Fig. 46 shows the exterior and the interior section of a Hancock inspirator. To inject water into the boiler, first open overflow valves *1* and *3*; close valve *2*; and open starting valve in the steam pipe. When the water appears at the overflow, open *2* one quarter-turn, close *1*, and then close *3*. The inspirator will then be in operation. When the inspirator is not working, open both *1* and *3* to allow water to drain from it.

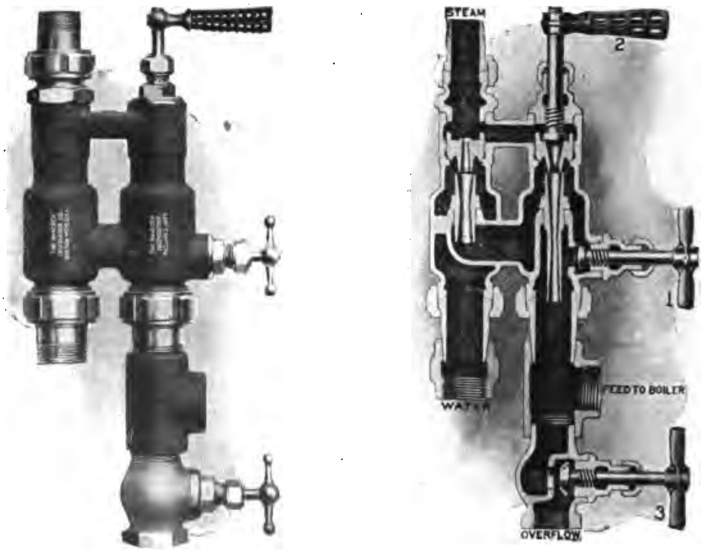

Fig. 46. Full and Sectional Views of Hancock Injector
Courtesy of Hancock Inspirator Company, Chicago, Ill.

Both the temperature and the quantity of delivery water can be varied by increasing or decreasing the water supply. When the water in the suction pipe is hot, either cool off both pipe and injector with cold water, or pump out the hot water by opening and closing the starting valve suddenly.

Centrifugal Pumps. Within recent years a method of feeding boilers by means of centrifugal pumps has come into favor. As the name implies, the action of the pump depends upon the centrifugal force obtained in the rapid revolution of a system of vanes attached to a shaft overcoming the pressure exerted in the discharge line. The accompanying illustration, Fig. 47, shows a section of a centrifugal pump without the driving motor or engine. The water intake is shown at the lower left-hand part of the cut; the revolving shaft is here shown carrying three vane systems or impellors placed alternately in series with stationary parts. Each pair, made up of a revolving disk and a stationary disk, is called a stage. When the shaft revolves, the water carried around the shaft by the first disk is thrown by centrifugal force away from the shaft and is guided into the next stage by the stationary disk. The next revolving disk receives the feed water at a pressure higher than that of the water at the source, and in turn impels it to the third stage at a still higher pressure.

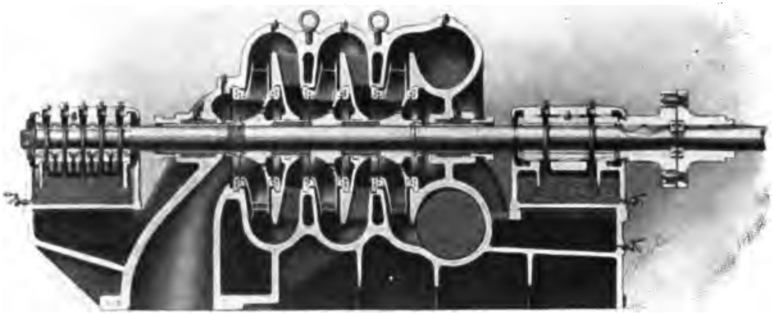

Fig. 47. Typical Section of a De Laval Multi-Stage Centrifugal Pump
Courtesy of De Laval Steam Turbine Company

The third stage performs the same service, and, when leaving the tips of the vanes of the third revolving disk, the water pressure is sufficient to overcome the pressure in the discharge pipe feeding the boiler.

Use for Boiler Feeding. In order to obtain success with the use of a centrifugal pump for boiler feeding, the design of the passages and the facilities for preventing communication between the stages, except by way of the ports provided, must be especially well cared for. In the illustration, note should be taken of the lubricating rings and the annular wearing rings on the faces of the disks. When a pump of this kind is directly connected to an electric motor or steam turbine, the whole constitutes a compact piece of apparatus.

Circulating Apparatus. There is always more or less danger in starting a fire under a boiler. If the circulation is poor, the result will be that not only will the water be of an uneven temperature—hot near the top and cold at the bottom—but the boiler shell is likely to be subjected to severe strain, owing to the difference of temperature arising from the stagnation of the cold water near the bottom. The fire must be started slowly, and considerable time consumed in getting up steam. To overcome the difficulty of poor circulation, several mechanical devices have been applied.

Injector. The first device tried was a hydrokineter—a sort of injector—in which jets of steam driven through a conical nozzle drew in the surrounding water. This was so arranged as to induce the cold water to flow from the bottom toward the top, where it was more intensely heated. This arrangement is efficient, but slow of action. In large marine boilers—in which the fire is cautiously started, as is proper—the temperature at the surface of the water, four hours after lighting up, has been found to be as high as 205°, while at the bottom it was only 73°. Several observations with a hydrokineter in action have shown the temperatures to be 205° and 144°, respectively. It was six hours more before the temperature was equalized throughout. In naval vessels, where it is frequently necessary to raise steam rapidly, this device is altogether too slow. It has, moreover, two other drawbacks. There must be an auxiliary boiler under steam pressure, and it will cease to act when the temperature and pressure of steam in the main boiler have reached those in the auxiliary boiler.

Feed-Water Jet. The steam jet, in the American Navy, has been replaced by a jet of feed water forced through a conical nozzle. This arrangement answers very well so long as steam is being drawn from the boiler; but when the boiler is at rest and steam is being raised, it is inoperative.

Small Centrifugal Pump. The best service is to be had by means of small centrifugal pumps fixed beside the boilers, which take water from the bottom of the boilers and discharge it a little below the water level. The pumps may be turned by hand while raising pressure, and may be worked by steam when sufficient pressure has been attained. A small engine of perhaps 1½ horsepower is sufficient to give a proper circulation to a large boiler. With such a circulating device, steam may be raised with safety in a comparatively short time.

REGULATING AND HEATING FEED WATER

Feed-Water Regulators. Strong claims are made for feed-water regulators as economical adjuncts to boiler equipment. Whether these claims are realized in practice depends largely upon the conditions under which the boiler plant is operated. Many engineers hold, on the contrary, that such devices should be avoided because their use creates a false sense of security in the minds of the operating force, which may give rise to carelessness on the part of the water tender and, at a time when something goes wrong with the regulator, operate to bring about a serious accident. That this is true generally can not be asserted positively, as the evidence seems to prove that feed-water regulators are good in some places and not in others. There are two kinds of regulators for feeding water; at least, the aims of manufacturers have developed along two distinct lines. By far the greater number of regulators are intended to insure a constant water level in the boiler, while there are several, more recently developed, whose object is to permit a varying water level, depending upon the demand for steam.

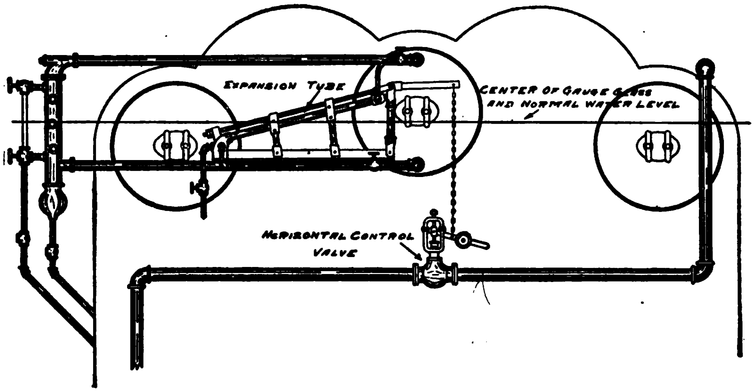

Fig. 48. Copes Regulator Installed for Submerged Tube Regulation on a Stirling Boiler; Feed Valve Horizontal
Courtesy of Northern Equipment Company, Erie, Pennsylvania

Varying Water-Level Regulator. Among the latter may be described the Copes regulator, illustrated in Fig. 48. In this figure the regulator part is shown as an adjunct to the water column.

The moving force is centered in the part "expansion tube", which is really a differential water column. As the expansion tube changes its length, it actuates a bell-crank lever which, by means of a chain, moves the stem of a balanced regulator valve. The latter is shown in Fig. 49. The variation in length of the expansion tube is obtained by the variation of the height of the water in the tube. When the water is high, the average temperature of the tube is lower than when the water is low; consequently, the length of the tube is less.

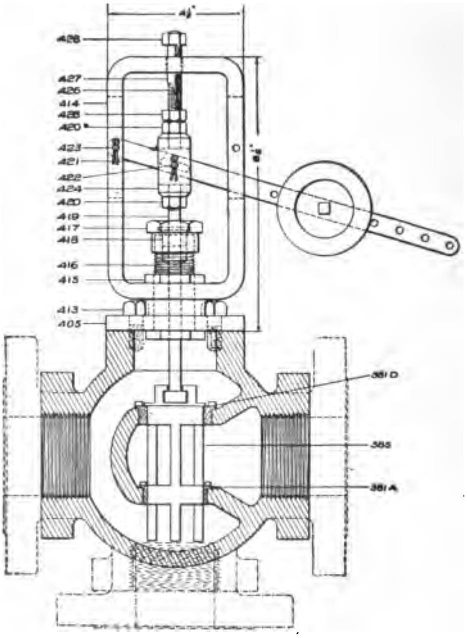

Fig. 49. Details of Type B H, Copes Feed Valve
Courtesy of Northern Equipment Company

The reason of its lower average temperature is that the water in the lower part of this inclined column is cooler than that in the stem above; the water in the tube radiates heat to the atmosphere, while the steam space retains the temperature corresponding to its pressure.

It is plain that, when the boiler load is light, the regulator tends to keep the water level high. This water tends to act as storage water against the time when the load becomes heavier. The reverse is true when the load is heavy, the regulator tending to reduce the water fed to the boiler to the amount required, until an opportunity has been given to create more steam by an increase of draft and greater coal consumption. Fig. 50 shows the Copes Submerged Tube Regulator, as installed on the usual fire-tube boiler.

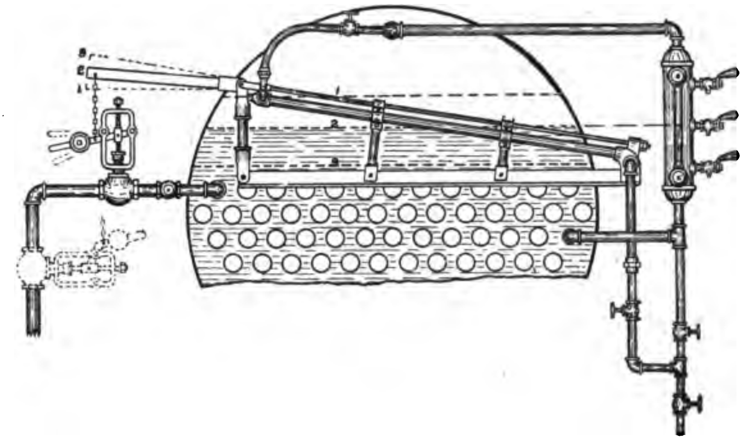

Fig. 50. Diagram of Copes Submerged Tube Regulator as Installed to Regulate Feed with Variable Water Level
Courtesy of Northern Equipment Company

Constant Water-Level Regulator. As an example of the type of regulator intended to maintain a constant water level may be mentioned the Liberty, Fig. 51. A study of the illustration will disclose the operation. The column on the left is in communication with the water of the boiler at such a height that a normal level of water in the boiler will stand at the middle of the column. When the water in the boiler starts to rise, it has the effect of raising the float, which, in turn, communicates with the lever system at its upper extremity. From this point the action is simple enough to be understood by examining the figure closely. The regulator control valve is shown on the right of the float column.

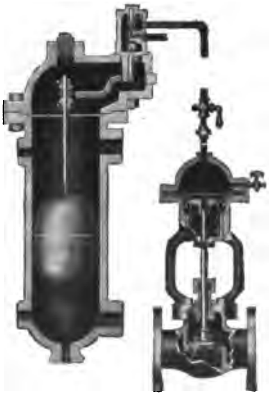

Fig. 51. Liberty Feed-Water Regulator
Courtesy of Elliott Company

Evaporators. No boiler can be run without a certain loss of water, due either to a slight continuous leakage or to blowing off.

In stationary practice, this loss can be readily made up by the introduction of fresh water; but at sea it is seldom possible to carry a sufficient amount of fresh water, and the make-up must be had either from sea water, or from fresh water provided by the use of an evaporator. The evaporator is really a small boiler, the water in which is heated by a steam coil supplied from the main boiler. The evaporated water—called the evaporation—passes into the condenser and then becomes a part of the regular feed water.

In a single evaporator, if the evaporation passes directly to the condenser, its heat is lost to useful work. To provide a more economical arrangement, multiple evaporators are installed. These consist of a series, the evaporation from the first passing into a coil in the bottom of the second; the water in the second condenses the evaporation from the first, while at the same time the evaporation from the first helps to heat the water of the second. The steam and water pass through the series of heaters in opposite directions.

It is a rule in the French Navy to provide 380 pounds of fresh water per hour for each 1,000 indicated horsepower. This provides for a loss of about 2 per cent without drawing on the reserve supply, which is 4,500 pounds for the same amount of power.

The evaporator may be arranged to communicate with a low-pressure valve chest, in which case the evaporation may be made to do work in a low-pressure cylinder of a triple-expansion engine before entering the condenser, or it may be connected with the feed-water heater if the exhaust steam is inadequate.

Feed-Water Heaters. *Economy Factor.* The introduction of feed water at a high temperature increases the economy and tends to prolong the life of the boiler. The injurious effects from unequal expansion are diminished; and when the feed water is warmed by exhaust steam or by the waste gases in the uptake, the saving of fuel is considerable. It may be safely stated that of all boiler-room accessories, feed-water heaters have the best claim as producers of economy.

If this gain comes from waste gases or exhaust steam, which would otherwise make no return for their heat, the gain is clear; but there is no gain in thermal economy by heating feed water with live steam directly from the boiler. In the latter case there is a distinct loss.

Methods Used. There are several ways of heating the feed water. In condensing engines, the feed pump discharges from the condenser into the hot well, and the water is drawn from the hot well as boiler feed, at a temperature of 100° to 140° F. This, however, if the pressure is over 100 pounds, is entirely inadequate; and for the best economy, feed water at this temperature should be passed through some form of feed-water heater. With noncondensing engines, it is absolutely necessary that in some way the feed water should be heated by the exhaust steam or by waste gases from the chimney, the apparatus in the first case being called a feed-water heater, and in the second, an economizer.

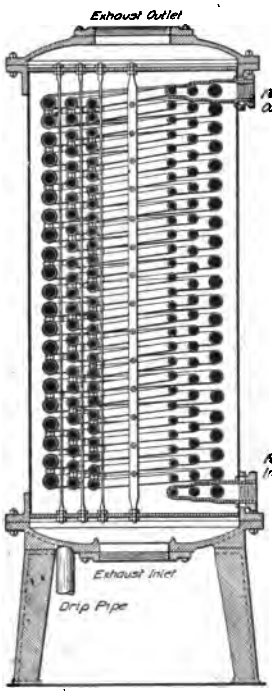

Fig. 52. Feed-Water Heater, Closed Type

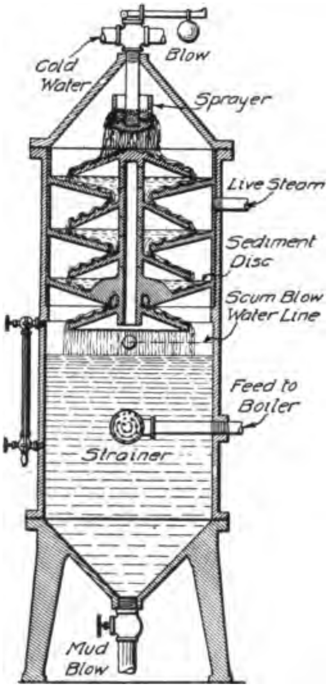

Fig. 53. Feed-Water Heater, Open Type

A feed-water heater may be arranged so that it will not only heat the water, but will at the same time purify it, precipitating the calcium and magnesia salts, which collect on suitably prepared plates, and gathering, at the bottom of the heater, dirt and other sediment which would injure the boiler or cause it to operate uneconomically.

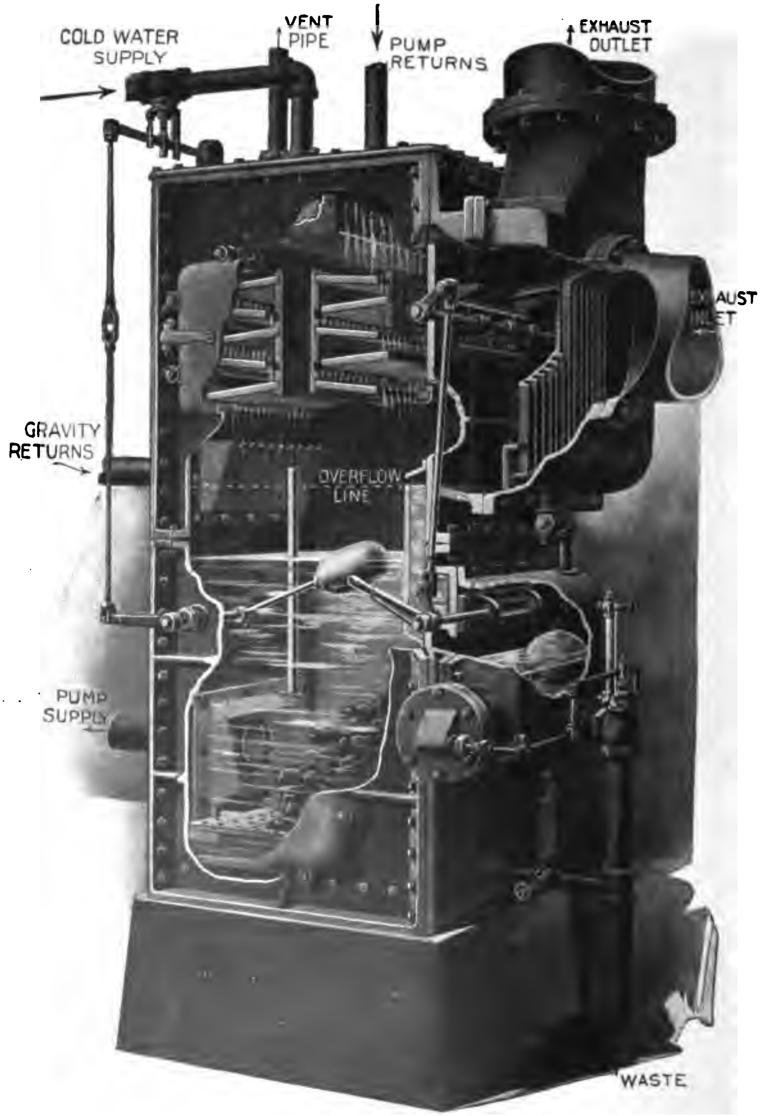

Fig. 54. Interior View of Cochrane Heater and Receiver
Courtesy of Harrison Safety Boiler Works

Types of Heaters. There are two types of feed-water heater—the open, which is frequently used in land work; and the closed, which may be used either on land or at sea. In the open heater, the steam raises the temperature of the water by mingling with it in direct contact. The closed type of heater resembles in its action a surface condenser; the steam used for heating purposes surrounds tubes which contain the feed water, or the water circulates about tubes through which the heating steam passes.

Fig. 52 shows a feed-water heater of the closed type, the exhaust steam heating the feed water within the tubes. The heater shown in Fig. 53 is of the open type, the feed water becoming heated and depositing sediment while flowing from one tray to another.

The Cochrane heater, Fig. 54, is a combined heater and purifier of the open-heater type, the water entering at the top and flowing in a thin sheet over a series of trays. The exhaust steam enters through the oil separator and, rising among the trays, heats the water to about 210° F, the action being similar to that of a jet condenser.

Skimmers. Boiler feed water, if taken from rivers or ponds, is likely to contain vegetable matter as well as solid materials. The vegetable matter will usually float to the surface, while the solids will collect at the bottom. To keep the boiler free from such impurities, it is customary to provide two blow-outs—a surface blow-out or skimmer, to take care of what rises to the top; and a bottom blow-out, to take out the sediment that collects at the bottom of the boiler. The surface blow-out usually consists of a dish or funnel-shaped receptacle set with its face vertical, as shown in Fig. 55. When the water level is in line with this blow-out opening, the opening of the valve will skim the impurities from the surface of the water. Oil may get into the boiler through the feed water, and a considerable portion of it can be removed in this manner.

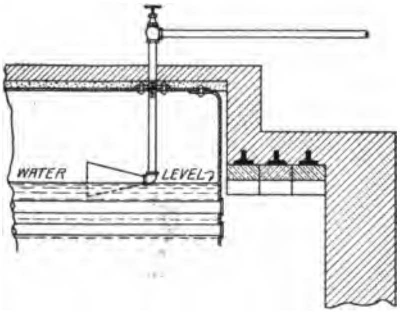

Fig. 55. Section of Boiler Showing Method of Installing Surface Blow-Out

Bottom Blow-Out. The bottom blow-out consists merely of a pipe leading from the bottom of the boiler outward. Both these blow-outs may be connected into one outlet.

Water-Tube Arrangement. In water-tube boilers a mud drum is usually installed, which collects the solid matter, and the bottom blow-out is then connected with this mud drum.

Marine Practice. In Fig. 43 is shown an arrangement of surface and bottom blow-outs as usually installed on a Scotch boiler of the marine type. If the feed water contains salt, which may frequently happen in marine practice, it is necessary that the boiler should be blown out frequently in order to remove the excess of salt. The heat losses due to this frequent blowing out are considerable, but they cannot be avoided, except by the use of fresh water, which sometimes may be impossible at sea. The density of the boiler water, if salt feed is used, should be carefully determined by a salimeter.

Protection for Blow-Out Pipe. The blow-out pipe leading from the bottom of an externally-fired boiler through the brick setting, if not properly protected, may be burned off, owing to the heat of the fire. This pipe is frequently covered with asbestos or other fire-resisting material; but it can be best protected by the means shown in Fig. 56. A pipe connected to the boiler slightly below the water level runs out through the brick setting and connects into the main blow-out pipe. This causes a circulation of water to pass continuously through the system, and prevents destruction of the blow-out pipe. When it is necessary to use the bottom blow-out, the valve A is closed, and the blow-off valve B is opened; otherwise, B is closed, and A is open while the water circulates.

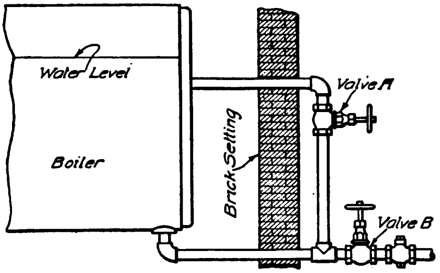

Fig. 56. Method of Protecting Bottom Blow-Out Pipe by Means of Circulation Pipe Connected to Boiler

Provision for Shutting Off Blow-Out Pipes. The blow-out pipe is usually shut off by a cock, which, although not so easily operated as a valve, is more trustworthy. Usually both a cock and a valve are provided. Should a small particle of sediment lodge on the valve seat, it would be impossible to close the valve tightly, and considerable leakage would result, while an inspection of the valve would not indicate whether it was completely closed or not. But a glance reveals the fact whether or not a cock is tightly closed. The cock is likely to stick because of corrosion or unequal expansion, but, if it is frequently opened, this difficulty is not of great weight.

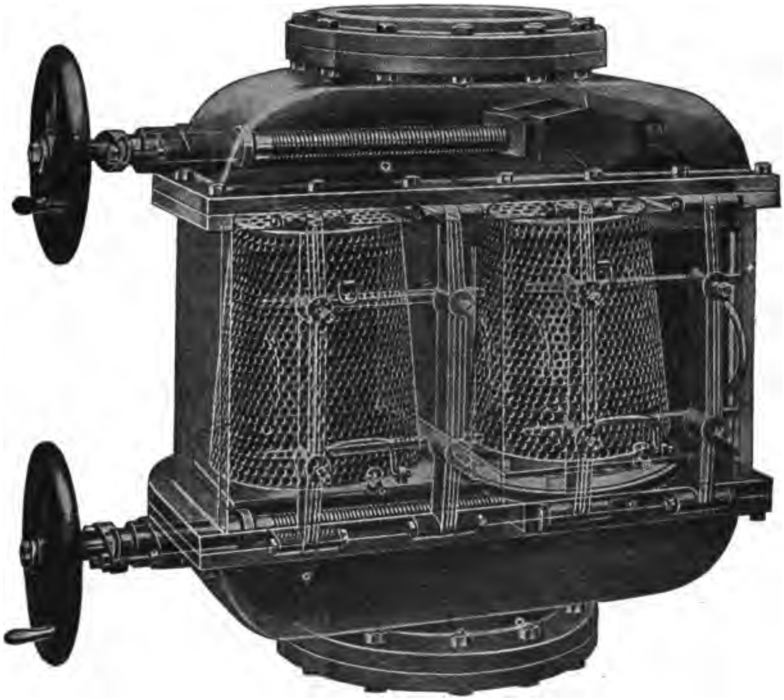

Fig. 57. Typical Twin Strainer
Courtesy of Elliott Company, Pittsburgh, Pennsylvania

The plug and casing of the cock should not be made of the same material, as, in that case, they will more readily stick if the cock remains closed any length of time.

Automatic Skimmer Systems. Several skimmers have been devised which are intended to operate automatically in the sense that, by their use, the surface impurities are constantly carried away from the boiler proper through the skimmer funnel and the adjoined piping. This piping, which is external to the boiler proper, but

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carries boiler pressure, leads to a settling chamber, a return lead of piping entering the water space of the boiler below the water surface but above the lower sediment chamber of the boiler. The principle of operation is to set up a slow circulation through the system due to the denser water of the external piping overbalancing a like column of water inside of the boiler, thus slowly carrying the surface impurities down to the settling chamber. Such a system should not be a direct part of the blow-off system to get the best results, and care should be taken that the return pipe will not cause the sediment to return to the boiler, as will occur if its connection with the settling chamber is too low down or too close to the deposit of sediment. In any case, the whole system must be suitably valved and contain facilities for independent blowing down. The blowing down should occur frequently.

Strainers. Where boiler feed water is likely to be taken from a source which permits the entrance of solids, such as ice, sticks, leaves, grass, cinders, wood, fish, eels, or any other kind of refuse, it is highly desirable to install a strainer which is exactly what the name implies. There are many forms of strainers, but all manufacturers aim to provide a device which will give uninterrupted service by so designing the equipment that the parts are easily removed and cleaned of the accumulated débris. The illustration, Fig. 57, shows a *twin* strainer which has the advantage of being two strainers so valved that one side can be operating while the other is opened for cleaning.

STEAM END AUXILIARIES

SUPERHEATERS

Reasons for Use of Superheaters. As the science of steam use has gradually progressed under the constant search for better means for creating and using heat energy, engineers have endeavored to overcome inherent heat losses in the transmission of steam through distances and by reason of cylinder condensation in engines. The early adoption of the *steam jacket* on engines had the same end in view so far as engine performance was concerned, but it was discovered that, while such a scheme would reduce actual cylinder condensation, the net condensation of steam might easily be increased. On the principle that dry metal surfaces convey heat from surrounding media much less rapidly than wet surfaces, it soon became evident that superheated steam would overcome, to a large extent, uneconomical engine operation, because superheated steam is as dry as a so-called permanent gas. The use of superheated steam received its greatest impetus at the time steam turbines were introduced, not only on account of the greater thermodynamic advantage, but also on account of the reduction of the blade wear of both the stationary and moving parts. Its use in reciprocating engines, though recognized as an advantage thermodynamically, has not been so general on account of the difficulties which arise in lubricating the rubbing parts subjected to high temperatures. This introductory statement is made in order to indicate that superheaters are used solely for their economical advantages, and not in any way because they tend to make the work of boiler-room operation less complicated, although it is to be said that a good superheater should not increase the complication of anything except, perhaps, the initial installation.

Types. *Direct Connected and Separately Fired.* There are two types of superheaters: those which form a part of the pressure construction of the boiler and are enclosed within the same structure as the boiler, and those which are separately fired. The latter type differs in no way from the attached type, both consisting of pipe coils placed where high temperature gas impinges upon them. The steam to be superheated passes through the coils on the inside, and the gas among the tubes or coils on the outside. The separately-fired type is necessary where the boiler construction is not adapted to the attachment of the coils within the path of the gases passing through or around the boiler-heating surface, or in cases where

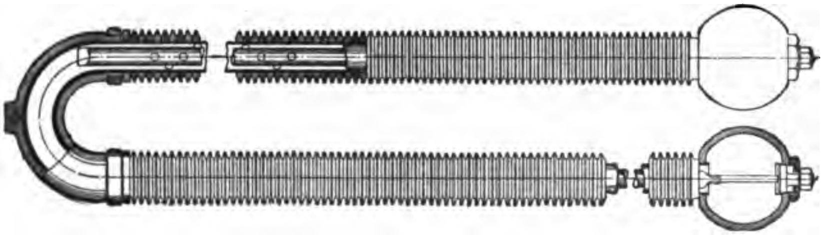

Fig. 58. Cross-Sectional View of Return-Bend Element and Connecting Headers Used in the Construction of Foster Superheaters
Courtesy of Power Specialty Company

extremely high temperature superheated steam is required in some manufacturing process.

Armored and Bare Coils. Two kinds of coils are in general use—bare tubes or coils and armored coils. Both kinds of superheaters may or may not have internal blind-end insertions of pipe in order to force the steam being superheated to pass along the tube surface in a thin sheet, thus making the coil superheating surface much more effective.

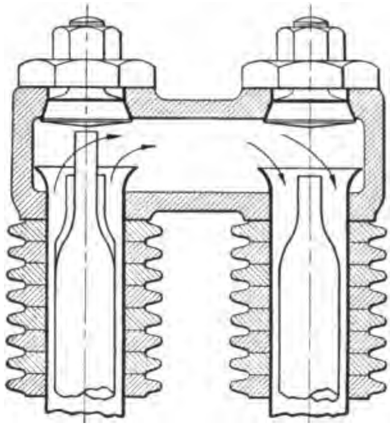

Fig. 59. Enlarged Section through Return Header Plugs

The leading make of armored superheater is known as the Foster, manufactured by the Power Specialty Company, New York City, Figs. 58, 59, and 60. Fig. 58 shows a single element partly cut away to expose the internal tubing. Fig. 59 shows a larger section through the return header plugs for the holes giving access to the header ends of the superheater element—cast-iron rings shrunk on a two-inch seamless tube, and the inner tube forcing the steam passing through to hug the coil surface.

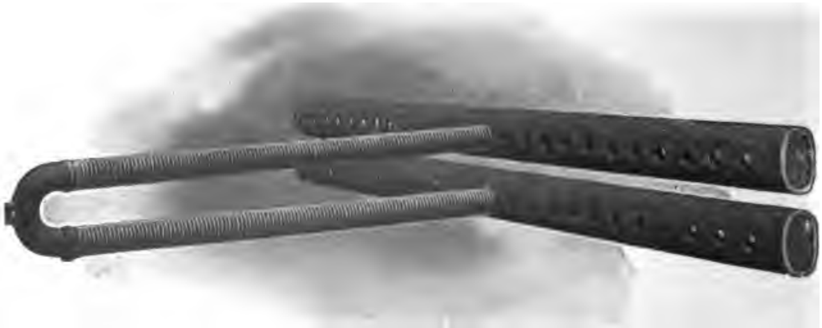

Fig. 60. One Protected Element of Foster Superheater, Showing Inlet and Outlet Headers
Courtesy of Power Specialty Company, New York City

Fig. 60 shows one element connected to two headers and a number of openings in both to accommodate a number of elements. The construction shown is that of the Foster superheater. The Babcock and Wilcox superheater is identical in shape, except that the element is not armored. Both superheaters are attached to boilers in practically the same manner and at the same locations. In operation and use, however, they are quite different, in that the Foster superheater, being armored, does not require "flooding"—a term used to indicate that water is introduced into the superheater coils at the starting up of the boiler until steam has actually been generated. The flooding is resorted to in bare-tube superheaters to preserve the coils from burning out during the time when no steam is given off by the boiler proper. The Foster arrangement, by presenting a protection of cast iron to the heated gases, delays the heating of the superheater tube proper until steam is actually generated and is passing through the superheated coils. The non-flooding type obviates the danger of sediment deposits from dirty water, and the still greater danger that a part of the flood water may remain in the coils even after steam is being delivered by the boiler, which, when a sudden demand for steam arises, may be carried in a mass and cause serious damage to either the piping or the engine.

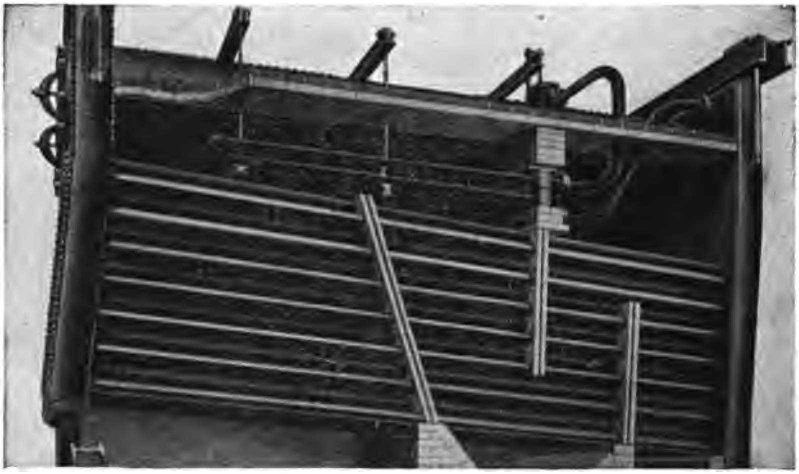

Fig. 61. Foster Superheater Mounted in Edge Moor Boiler

Fig. 61 illustrates only one of many forms of superheater installations in use. The boiler shown is a water-tube boiler of the horizontal type, and the superheater is shown by the loops or elements placed between the boiler drums and the top row of tubes of the boiler proper. It will be noted that the superheater coils are not subjected to the intense heat of the gases immediately after being generated in the furnace, but receive this gas after passing among the boiler tubes in its first pass. The superheater receives its steam from the steam space in the rear header of the boiler and delivers it from the upper manifold.

STEAM SEPARATORS

Danger of "Wet" Steam. Steam is said to be wet or to be superheated according as it carries entrained moisture, or is of a temperature higher than that of saturated steam at the pressure dealt with. Wet steam is uneconomical to use, not only because it induces cylinder condensation in the engine, but because, if a considerable amount of water gets into the engine, it is really dangerous, for it may so completely fill the clearances that the piston will strike a blow against the cylinder head sufficient to break it. The water in the pipes, moreover, may cause a serious hammering, which not only is annoying, but may be actually hazardous, for a severe water hammer may break the joints of the steam pipes, and a large quantity of escaping steam at high pressure would be exceedingly dangerous to the lives of the engine-room attendants. This is especially true on board ship, where the engine room is small, the supply of air meager, and the means of escape limited.

A considerable amount of water may be deposited in the sag of an improperly built pipe line, and may remain there for an indefinite length of time if the pressure in the boiler does not fluctuate; but a sudden rise of boiler pressure will likely cause this water to pass bodily through the pipe toward the engine.

Priming. When a boiler delivers steam containing entrained moisture, it is said to *prime.* The presence of any substance which tends to increase the surface tension of the water, such as grease, oil, or other foreign matter, increases the priming tendency. If the boiler is such that the steam in entering into the space containing the boiler dry pipe is projected near the dry-pipe openings, the result is much entrained moisture in the steam. When a boiler, working at a fairly uniform rate, is suddenly called upon to deliver a somewhat greater quantity of steam and the fire conditions are correspondingly improved, the water level is raised on account of a greater percentage of steam bubbles in the water mass; and the result may be that the level of the water approaches so close to the steam outlet pipe that the steam, rushing toward its opening, carries large quantities of suspended moisture with it. If the water foams badly and the foregoing event takes place, the amount of moisture carried along with the steam may be quite large.

Priming may be detected from the unusual behavior of the water in the gage glass, or from the hammering in the steam pipes or engine cylinder. To avoid a breakdown under such conditions, the speed of the engine should be reduced, the drain cocks of the cylinders and pipes opened, and the fires eased down. Sometimes, by suddenly shutting the main stop valve, the pressure in the boiler can be increased sufficiently to overcome the difficulty.

Simple Methods of Obtaining Dry Steam. *Steam Dome.* Almost any boiler is likely to prime to some extent; and, to obtain as dry steam as possible, several devices are employed. On the top of stationary boilers and locomotives, a steam dome is frequently built, from which the steam is drawn, the idea being that less moisture will be found here than if the steam be drawn directly from the main portion of the boiler.

Dry Pipe Method. In marine work, and sometimes in stationary plants, a dry pipe is used, Fig. 43. This is merely a large pipe inside the boiler from which the steam is drawn. The pipe is near the top of the boiler, and the upper side of it is perforated with holes through which the steam may pass. In this way a considerable amount of moisture is prevented from leaving the boiler.

The moisture in steam can be reduced by the familiar process of superheating; but if this, for any reason, is impracticable or undesirable, a steam separator may be used for the purpose of extracting the moisture which comes from the priming of the boiler or from condensation in the steam pipe.

Types of Steam Separators. There are several forms of separators; but all are designed on the general principle that if the direction of the steam current is suddenly changed, or if it is diverted upward and then downward, the water will be separated from the steam and will fall to the bottom of a suitable receptacle. The depth of water collected in the bottom of the separator is readily indicated by a gage glass, and it may be drawn off as desired. To prevent the possibility of flooding the separator, it is well to connect it with an automatic trap which will empty it without close attention from the engineer. It is needless, of course, to say that the trap from this separator should be connected to the hot well, and the drip should be returned to the boiler with the loss of as little heat as possible.

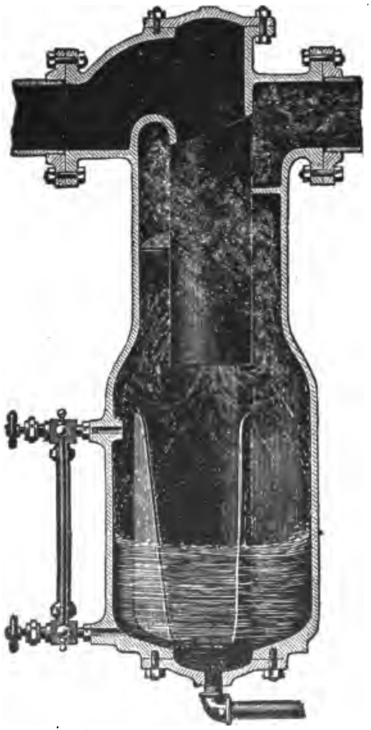

Fig. 62. Stratton Separator
Courtesy of Griscom-Russell Company

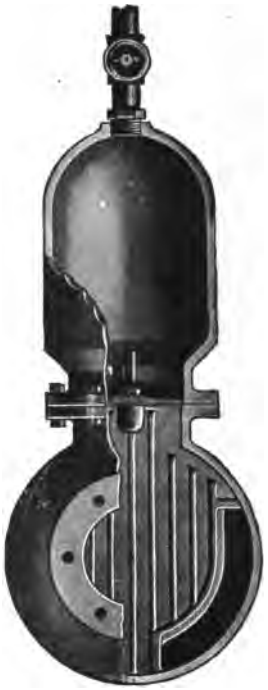

Fig. 63. Cochrane Separator
Courtesy of Harrison Safety Boiler Works

In the Stratton separator, Fig. 62, the steam enters at one side of a cylinder, flows downward, and then upward through a pipe in the middle. Dry steam escapes from a pipe near the top on the opposite side from which it enters. The separated water is drained at the bottom.

The Cochrane steam separator, Fig. 63, is of the baffle-plate type. The branches for the entrance and exit of the steam project from each side of the spherical head. Another branch from the bottom provides for connection with the well. The baffle plate, which is cast as a part of the head, is ribbed, or corrugated, and has ports at each side for the passage of steam. The area of the ports is large, to prevent loss by friction. A small pipe is inserted in the plate on the outlet side at the bottom of the baffle plate, to drain any condensation in the outlet chamber. Steam, entering at the left-hand opening, strikes the baffle plate and passes to the outlet chamber by means of the two side passages, as shown in Fig. 63.

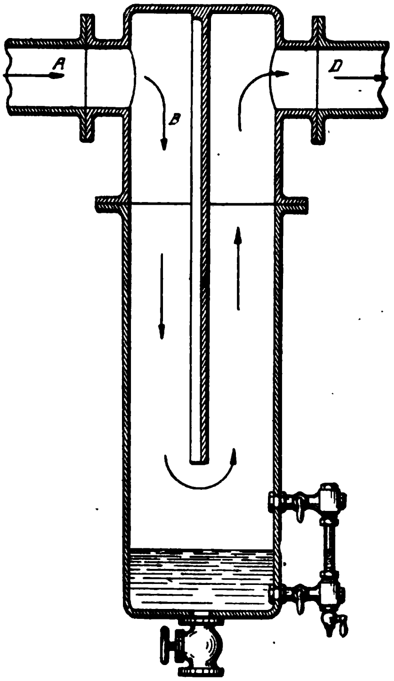

Fig. 64. Separator Designed for Connection to Main Steam Pipe Near Engine

A form of separator which is fitted to the main steam pipe near the engine is shown in Fig. 64. Steam enters at *A* and strikes the dash plate *B;* any water coming with the steam is separated and falls to the bottom. The steam takes the direction indicated by the arrows, and flows out at *D*. This separator is fitted with a gage glass which is similar to a boiler gage glass.

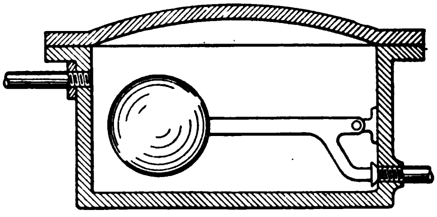

Fig. 65. Simple Steam Trap Operated by Float

TRAPS

Steam Traps. Steam traps are used for collecting the water of condensation from steam pipes. They consist of a receptacle with an inlet and outlet valve so arranged that the condensation which collects may flow out, but steam cannot pass.

Float Type. In the float trap shown in Fig. 65, the float rises and falls with the change in water level. When the water level rises above a certain point, the float opens the discharge valve. The trap shown in Fig. 66 is similar, the float being replaced by a weight *W*, which is nearly counterbalanced by the weight *T*. The raising of *W* by the water opens the valve *V*.

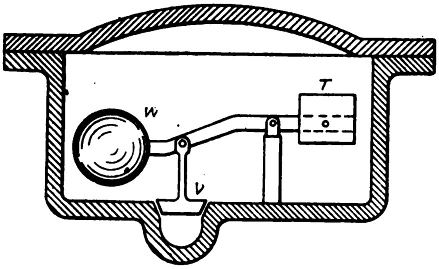

Fig. 66. Steam Trap Operated by Nearly Counterbalanced Weight

Bucket Type. There are other forms called bucket traps. In the one shown in Fig. 67, the water enters at *W*. While there is only a little water around the bucket *F*, it floats, and the valve *V* is closed; but when the water rises high enough to flow over the edge, the weight of water in the bucket causes it to sink, and opens the valve *V*. Water is forced up the passage *M*, and out through the pipe *N*, by the pressure of the steam on the surface of the water surrounding the bucket.

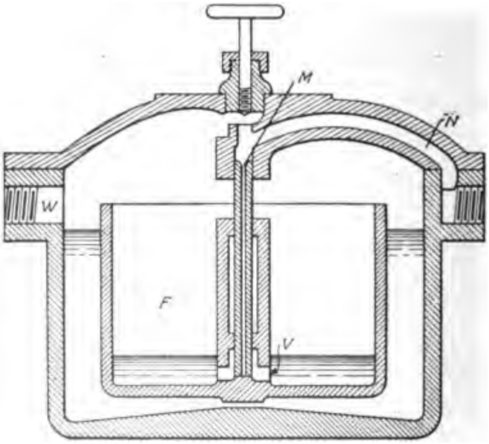

Fig. 67. Bucket Type of Steam Trap

Differential Type. Another form of trap, called the differential steam trap, depends upon a head of water acting on a flexible diaphragm. Water enters at either top or bottom by the pipes *E*, Fig. 68. When the water level rises it fills the chamber *G* and the pipe *N*. This causes a pressure on the under side of the diaphragm greater than that caused by the spring *H*, which spring acts on the upper side of the diaphragm and tends to keep the valve open. While the pressure below the diaphragm preponderates, the valve *P* remains closed. When the water rises and fills the chamber *J* so as to flow down the pipe *M*, the water pressure on the upper and lower side of the diaphragm will become equal, because the head of water in *M* is practically the same as that in *N*. The spring will now open the valve *P*, and water will be discharged from the pipe *I*. When the head in *M* falls, the pressure on the under side of the diaphragm again becomes greater, and the valve accordingly closes.

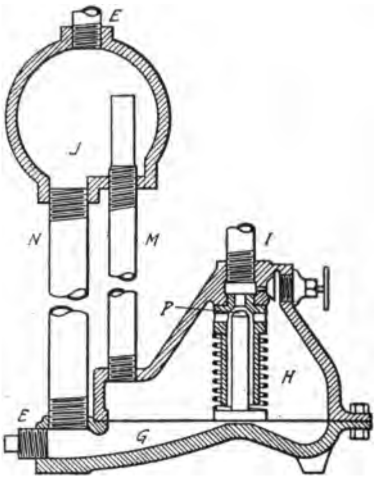

Fig. 68. Differential Steam Trap Operated by Water Pressure on a Flexible Diaphragm

Return Traps. Traps that are used for returning water of condensation to the boiler are called return traps. The object is to

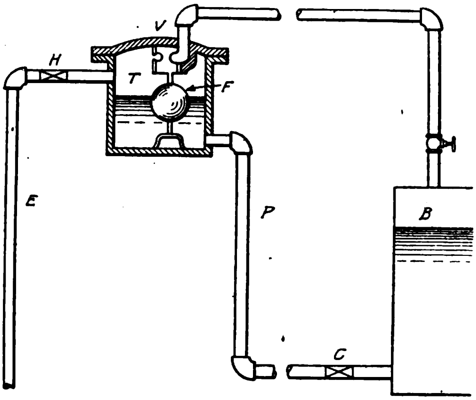

Fig. 69. Diagram Illustrating Operation of Return Trap

reclaim the steam condensed in piping, which would otherwise be lost. There is a variety of forms, but the principle of action is similar in all and is shown in Fig. 69. *B* represents the boiler and *T* the trap, which is placed a few feet above the boiler. The trap is supplied with steam from the boiler. It is also connected with the boiler by the pipe *P*, in which is a check valve *C*. Water of condensation enters the trap through the pipe *E*, in which is a check valve *H*, until it reaches a depth sufficient to raise the float *F*, which opens the balanced steam valve *V*, called an equalizing valve. Steam from the boiler then enters the trap and equalizes the pressure. Since the pressures are equal, water in the trap, because of its height above the water level of the boiler, will flow to the boiler until the level in the pipe *P* is nearly the same as the water level in the boiler. As the water level in the trap falls, the float *F* drops, and the equalizing valve is closed. In some forms of return traps buckets are used instead of floats.

SOOT BLOWERS

Causes of Soot. The whole subject of soot arises out of the effects surrounding incomplete combustion, of whatever form that may take. Therefore, the causes, effects, and remedies having to do with incomplete or partial combustion are inseparably linked with soot formation. If the combustion process is looked after effectually the soot problem becomes less in extent. Primarily the main loss from soot formation is the decrease in the absorbing ability of the heating surfaces rather than the loss due to the amount of fuel unburned and rejected as soot. Corrosion of boiler parts is sometimes caused by the acid action of a combination of the sulphur

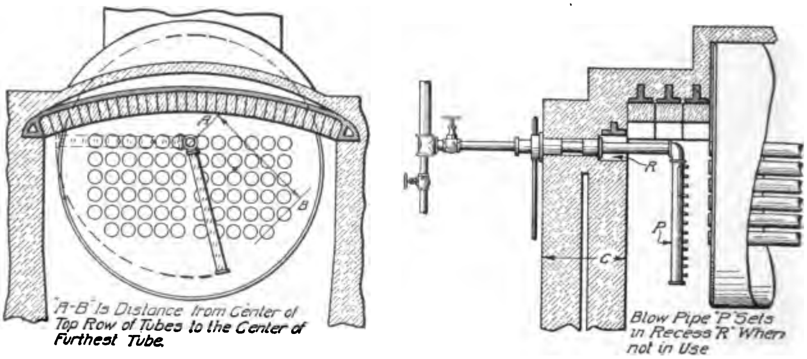
A
B
"A-B" Is Distance from Center of Top Row of Tubes to the Center of Furthest Tube.
R
P
C
Blow Pipe "P" Sets in Recess "R" When not in Use

Fig. 70. Application of Vulcan Soot Blower to Horizontal Fire-Tube Boiler

products of combustion uniting with moisture of which the soot acts as a ready absorbent.

Methods of Removal of Soot. The removal of soot presents difficulties which require ingenuity on the part of both the designing and operating engineers of steam plants. It has developed that soot of a given thickness on heating surface is somewhat more serious in the reduction of boiler economy than an equal thickness of scale deposited by evaporated water. The problem in fire-tube boilers is less difficult than with water-tube boilers for the same reason that the reverse is true in the matter of scale removal.

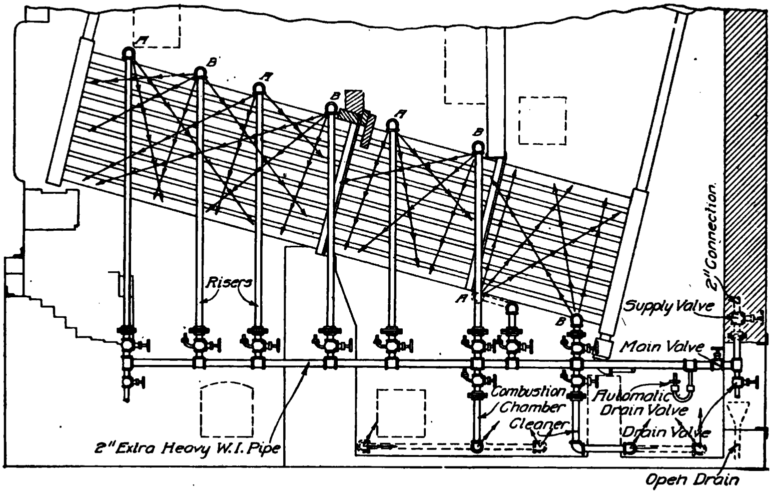

Fig. 71. Side View of Vulcan Soot Blower as Applied to Single-Deck Horizontal Water-Tube Boiler with Vertical Baffles
Courtesy of Vulcan Fuel Economy Company, Chicago

Fire-Tube Boiler Type. In fire-tube boilers the soot cleaning is done by inserting a pipe leading to either air or steam under pressure in the end of each tube, thus creating a high velocity of gas or steam movement in that particular tube which scrubs out the soot. If the process is continued, and soot is not blown from one part of the boiler to another, results are fairly satisfactory.

An improvement in the manual cleaning can be obtained by the device shown in Fig. 70. This blower—shown in the illustration as ready for use—performs the entire blowing service by rotating the blower arm so that jets of steam blow down each tube. The cleaning is done rapidly, and the soot is forced to go in the direction of the gas travel or toward the chimney. When not in use the blower pipe is withdrawn into a recess in the back wall of the boiler setting, thus removing it from the hot gases.

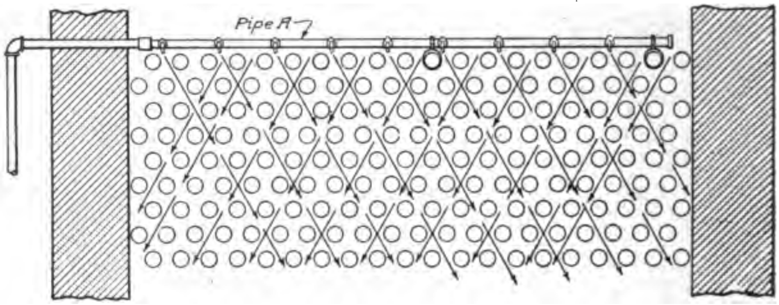

Fig. 72. Section through Tubes Showing Location of Nozzles of Vulcan Soot Blower

Water-Tube Boiler Type. Soot blowers for water-tube boilers must be designed to fit the boiler settings and baffling arrangements, which are almost as numerous as the types of water-tube boilers manufactured. Only two arrangements can be shown here.

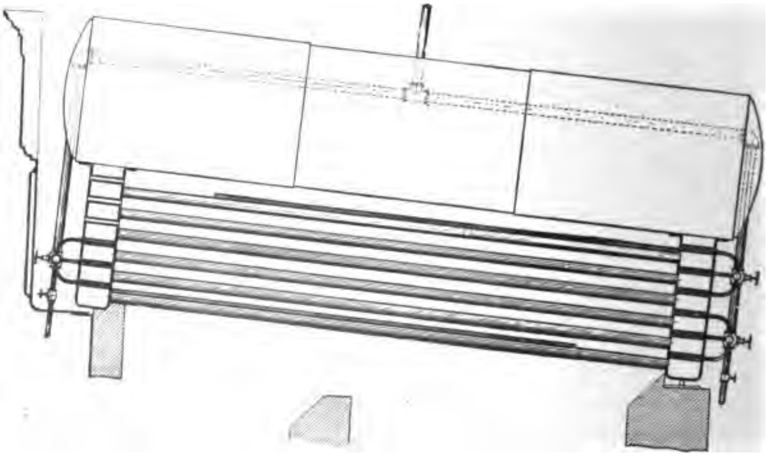

Fig. 73. Type of Double-End Soot Blower Attached to Water-Tube Boiler
Courtesy of Diamond Power Specialty Company, Detroit, Michigan

Fig. 71 illustrates a system adapted for use with a horizontal water-tube boiler. The intention is here to keep the cross blowing pipes out of the heated gases until a part of the heat has been extracted. The number of openings in the setting wall are reduced to a minimum and ample facilities for drainage are provided. Fig. 72 shows the direction taken by the steam jets.

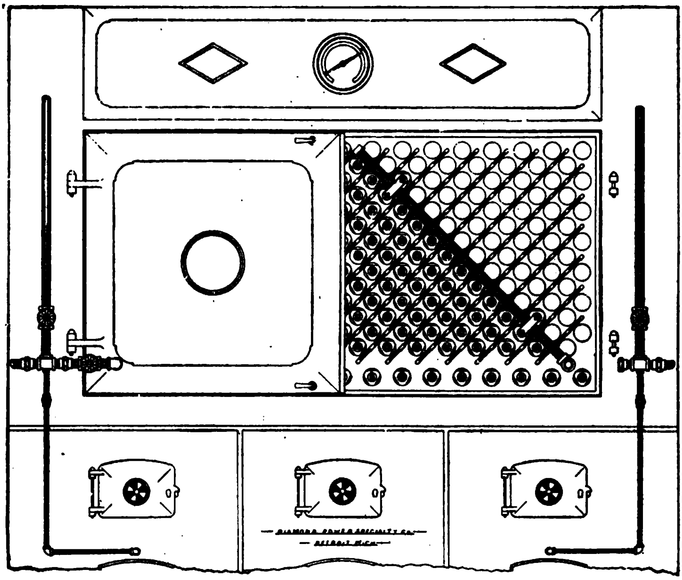

Fig. 74. Single-End Soot Blower for Boilers Having Hollow Stays
Courtesy of Diamond Power Specialty Company, Detroit, Michigan

Some types of boilers do not permit side access to the boiler tubes, in which case other means must be resorted to than those given in Fig. 71. Figs. 73 and 74 show one method employed where advantage is taken of the hollow stay bolts of water-leg boilers. Fig. 73 illustrates an older double-end type while Fig. 74 shows a new type of single-end soot blower. The manner of introducing the blower into a hollow stay bolt is shown in Fig. 75. The illustration is sufficiently clear to show its application.

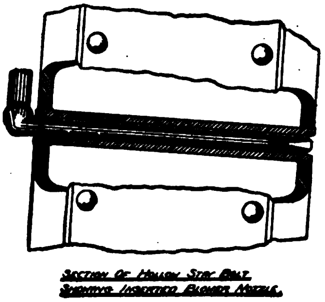

Fig. 75. Diagram Showing Attachment of Blower to Hollow Stay

LAGGING

Necessity for Protection. When steam pipes are exposed to the air, a considerable amount of condensation will collect in them, depending upon the condition of the surface of the pipe, on the differ-

TABLE I

Bare Pipe Data

Heat Losses in Bare Pipes		Variation of Heat Loss with Pressure	
Condition of Pipe	B.t.u. Loss per Sq. Ft. per Minute	Pressure	Heat Loss B.t.u. per Sq. Ft. per Minute
New pipe	11.96	340	15.97
Painted glossy black	12.10	200	13.84
Painted glossy white	12.02	100	8.92
Fair condition	13.84	80	8.04
Rusty	14.20	60	7.00
Coated with cylinder oil	13.90	40	5.74
Painted dull black	14.40		

ence in temperature between the steam and the surrounding air, and on the velocity of the steam through the pipe. This condensation will cause a large amount of heat to be lost to useful work, and will make the dangers of water hammer possible unless carefully drained. Tests have shown that about 2 B.t.u. are lost per square foot of pipe per hour per degree of difference in temperature. While the loss for a few hours is not likely to be great, yet, if taken for an entire year throughout a considerable length of pipe, the sum total will be very large indeed. Table I* gives some idea of the loss of heat through bare pipe at 200 pounds pressure.

Pipe Coverings. To make this loss from radiation as small as possible, it is customary to cover the pipe or boiler with some material which will prevent loss of heat and which will not burn. There is considerable difference in the value of various substances as preventives of heat radiation. Their value varies nearly in an inverse ratio to their conducting power; but due allowance must be made for the possible deterioration of the pipe covering. Table II gives the relative value of various substances with reference to their ability to prevent radiation of heat. For purposes of comparison, the value of wool is taken as the standard.

Types of Covering. Many of the patented coverings are very efficient, but they are too numerous even to mention. The abovementioned article from the Proceedings of the American Society of

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*A full account of some interesting tests can be found in a paper entitled *Protection of Steam-Heating Surfaces*, by C. L. Norton, Vol. XIX, Proceedings of the American Society of Mechanical Engineers, from which Table I has been taken.

TABLE II

Relative Values of Various Preventives of Radiation of Heat

Materials	Per Cent of Value	Materials	Per Cent of Value
Felt, hair, or wool	100	Sawdust	61–68
Asbestos sponge	98	Asbestos paper	47
Air-cell asbestos	89	Wood	40–55
Mineral wool	68–83	Asbestos, fibrous	36
Carbonate of magnesia	67–76	Plaster of Paris	34
Charcoal	63	Air space (undivided)	22

Mechanical Engineers gives the results of tests of several of these coverings. A good protection is afforded by air confined in minute cells, such as is to be had in the air-cell asbestos board; this is made by cementing together several layers of asbestos paper which have been corrugated or indented by machinery so as to form minute air cells. The more minute the subdivision of these cells, the better the protection is likely to be. Hair felt is one of the most efficient non-conductors, because it is very porous and contains a large number of air cells. It is not one of the best coverings, however, because it is likely to deteriorate, and its life on high-pressure pipes is not likely to be more than four or five years. On low-pressure work it may last for a considerably longer time.

Mineral wool, a fibrous material made from blast-furnace slag, is an efficient and noncombustible covering, but is brittle and liable to fall off.

The coverings most easily applied to pipes are those which can be applied in sectional form. They clasp around the pipe and are fastened by brass bands at convenient intervals. Such coverings are made either of asbestos or magnesia, and are usually about one inch thick for the smaller sizes of pipe.

A good, cheap covering can be made by wrapping several layers of asbestos paper around the pipe, and then putting over this a layer of hair felt three-fourths inch thick, the whole being wrapped in canvas. On low-pressure steam pipes this covering will last ten to fifteen years.

Cork is perhaps one of the most satisfactory coverings from the point of radiation loss, but is somewhat more expensive than asbestos or magnesia.

Cost. It has been the general impression that it is not economical to cover a pipe to more than one inch in thickness. This will depend upon the cost of the covering and the length of time it is likely to last. If it does not last more than five years, one inch is probably the most economical thickness; but if the life of the covering is likely to be ten years or more, a second inch in thickness can be applied to advantage. For instance, in the above-mentioned tests, in the case of Nonpareil cork, increasing the thickness from one to two inches raised the cost from $25 to $30 per 100 square feet, and increased the net saving in five years by $10, and by $30 in ten years. A third inch of covering did not produce saving enough to pay for its cost. In each case with the asbestos fireboard, a second inch in thickness showed a saving of $20 in ten years, while the third inch in thickness showed an actual loss from the dollars-and-cents point of view. It should be remembered that it is of great importance that to keep the pipe covering in repair, for a loose-fitting covering is of little value.

Boiler Coverings. The same may be said with regard to boiler as to pipe covering, except that the covering put on boilers is usually somewhat less efficient and is applied in greater thickness. Probably one of the best coverings for a marine boiler—or, in fact, for any internally-fired boiler—is a layer of air-cell asbestos board, covered with a coating perhaps two inches thick of magnesia or asbestos. This comes in powder form, and when mixed with water can be readily applied with a trowel. Coverings on boilers are best placed directly against the shell without an air space, so that any leak in a joint or rivet will reveal the spot by moistening the covering; otherwise the escaping water may run down through the air space and appear at some remote point, thus making the leak difficult to locate.

An efficient covering for boilers is made of either magnesia or asbestos in the form of blocks of the proper curvature, which can lie directly against the boiler; but this form of covering is rather more expensive than the asbestos or magnesia cement. To secure an extra hard finish a coating of plaster of Paris may be put on outside the magnesia or asbestos. No boiler or pipe covering should contain sulphate of lime, as this is likely to cause corrosion.

Covering for Externally Fired Boiler. If an internally fired boiler is properly lagged, there is little danger that any large amount of heat will be lost, as the heat of the fire must pass through the water before radiating. This is not true with an externally fired boiler, where a considerable amount of heat may radiate through the brick setting of the boiler without coming in contact with the boiler at all.

Many expedients have been tried, most of them with indifferent success, to provide an efficient method of preventing heat radiation from the settings of externally fired boilers. The earlier attempts took the shape of building an air space in the boiler walls; this simple construction is not effective because the air can circulate easily between the walls and, even when the two walls are properly bonded together, the outer wall may be intact while the inner and more important wall may be badly cracked or crumbled. The better form of double or air-space wall divides the air space into noncommunicating cells of, say, 4 square feet of area. It is safe to say that air-space walls are finding less favor as the science of boiler economy is becoming more exact. However, it is quite necessary to apply some better insulation than that afforded by a brick masonry wall for boiler settings. Recent practice is tending to the application of magnesia or asbestos in a layer about 2 inches thick on the whole exterior surface of the usual brickwork, covering this in turn with canvas glued tight to the surface. Several coats of paint are then applied. When work of this kind is properly done, it not only reduces radiation of heat materially but prevents the infiltration of air into the settings, which is of much more importance.

DRAFT APPARATUS

General Classification. The entire subject of draft apparatus is closely linked with both the design and operation of boilers. Primarily, of course, the object of such equipment is to provide air for combustion, but as the manner of application is determined to a large extent upon boiler passages, tube rows, etc., it is thought proper to present the main features here, because the usual situation is that the boiler is located between the draft creator and the place where the effect is to be felt, namely, in the furnace. Even should the apparatus be such as to force the air for combustion through the furnace, the degree of freedom of permitting the gases to move from the furnace is still controlled largely by the boiler or its setting design. The terms used with reference to the way in which the draft force is created are descriptive of the contrivances themselves, namely, *natural,* if brought about by a permanent rigid structure, such as a chimney; *mechanical,* if fans, blowers, stack jets, etc., are used. The second group is divided into *forced* or *induced,* to express whether the air is acted upon mechanically before or after entering the combustion chamber.

CHIMNEYS

Action of Chimney. The proper design of chimneys constitutes one of the most important features to be dealt with in boiler practice, though the factors entering into stack design are so numerous that it has not, thus far, been practicable to evolve a formula including even most of the variables in one statement. Recourse is therefore taken to the results obtained in practice, expressions of which are found in empirical equations which must be very judiciously handled lest grave mistakes result.

The gas leaving a boiler setting, being somewhat hotter than the air surrounding the chimney it enters, weighs less than the same volume of air surrounding the chimney. If the air surrounding the chimney has access to the chimney, or can exert its weight upon the lighter gases within the chimney, even by the devious path through the setting of the boiler and its breeching, there will be a constant tendency to establish a balance between the two. The force tending to establish this balance is termed *draft.*

Determining Factors in Chimney Design. The purpose of providing a draft force at the chimney is to create a force to supply air to the burning fuel and to carry the gases of combustion through the boiler setting and connections to the chimney. The height of the chimney should then be sufficient to perform all the work of overcoming the fuel-bed resistance and the other passage resistances that may be encountered. From this it may be correctly judged that it is the height of a chimney which determines the intensity of draft for a given gas temperature and the maximum probable rate at which the fuel can be burned, while the area of the chimney controls the amount of gas in cubic feet per unit of time the chimney will carry away, considering a given temperature of gas. In further explanation of these two statements, attention need only be called to the fact that the higher a chimney the greater its cubical contents for a given area, and consequently the greater the difference between the interior and exterior gas columns in weight; that the rate at which fuel can be burned is nearly proportional to the difference in draft above and below the fuel bed.

It is true that both the area and the height of a chimney have some influence upon the draft intensity when a gas of a definite temperature is delivered to it, but it is customary to look upon the design of chimneys in the light stated, modifying both dimensions for structural reasons.

Dimensions of Chimneys by Kent's Formula. Many formulas have been advanced for the purpose of arriving at more exact methods for proportioning chimneys than by the unsatisfactory expedient of finding a chimney that has turned out well. Most of them leave so many factors unprovided for that it is now recognized as a mistake to use them except in the simplest cases. Probably the formula advanced by William Kent has received the most favorable consideration in the United States. Table III is computed by using the formula mentioned; a coal consumption of five pounds per horsepower developed is the basis of the computation. The results obtained by the use of this table are satisfactory, as there is a margin allowed for a reasonable overload. It is well to apply an increase to the height figures given in the table when low-grade bituminous coals are dealt with. Many engineers use a uniform increase of 20 per cent for this purpose, but there are circumstances when a much greater increase should be supplied. No definite rule can be given covering these contingencies.

Careful chimney designers make allowances for varying altitudes above the sea level. The reason is easily seen, for the density of air grows less as the height above the sea level is increased.

Influence of Fuel on Draft Required. The draft necessary for burning fuels other than coal is of different intensity than for coal. For a given boiler setting, wood should rarely be provided with as high a draft as for coal; for oil burning less draft is required at the chimney, as there is no fuel bed to offer resistance. In the latter instance the chimney may be of considerable less area also than for coal, because the volume of gas coming from oil economically burned is less than for coal burned at a rate to create the same power or evaporation.

Methods of Construction. Chimneys are usually made of brick, steel, or concrete. If of steel or concrete, they are always circular. When made of brick they are circular, rectangular, or octagonal. For a given area, a circular chimney requires the least material, since a circumference has the least perimeter; it also presents less resistance to wind.

A steel chimney is made up of plates of steel riveted together. The shell is bolted through a foundation ring of cast iron to the concrete foundation. It is sometimes lined with fire brick, with a thickness which varies from 12 to 18 inches at the bottom to about 2 inches to 4 inches at the top. This lining is used to prevent heat being lost through the shell and does not add to the strength of the chimney.

A brick chimney is built in two parts—the outer shell, which resists wind pressure, and a lining. The inner chimney is made separate from the external shell in order that it may expand when the chimney is carrying hot gases.

The interior surfaces of brick chimneys are often of cylindrical shape, while the exterior surface tapers. The taper is about .3 inch to the foot. The brick at the base of the chimney is splayed out to make a large base.

During recent years concrete chimneys have come into much favor, especially since this type of construction has been perfected both in strength and appearance. While the early concrete chimneys had cylindrical shafts they are now quite generally built with tapered shafts which not only reduces the amount of material required for their construction, but improves the appearance.

The concrete is reinforced with vertical steel rods and some form of woven wire mesh made up in rings. When proper concrete mixtures are used with good designs and are placed under the direction of competent construction superintendents, the results are quite satisfactory in concrete chimney work.

As good natural earth should carry from 2000 to 4000 pounds per square foot, the base of the chimney should be large enough so that this pressure will not be exceeded.

TABLE III

Stack Sizes by Kent's Formula

(Assuming 5 Pounds of Coal per Horsepower Hour)

Diameter (inches)	Area (square feet)	HEIGHT OF STACK IN FEET								Size of Equivalent Square Stack (inches)	Diameter (inches)
		70	80	90	100	110	125	150	175		
		COMMERCIAL HORSEPOWER									
33	5.94	125	133	141	149	156	....	....	....	30	33
36	7.07	152	163	173	182	191	204	....	....	32	36
39	8.30	183	196	208	219	229	245	268	....	35	39
42	9.62	216	231	245	258	271	289	316	342	38	42
48	12.57	....	311	330	348	365	389	426	460	43	48
54	15.90	....	....	427	449	472	503	551	595	48	54
60	19.64	....	....	536	565	593	632	692	748	54	60
66	23.76	....	....	....	694	728	776	849	918	59	66
72	28.27	....	....	....	835	876	934	1023	1105	64	72
78	33.18	....	....	....	....	1038	1107	1212	1310	70	78
84	38.48	....	....	....	....	1214	1294	1418	1531	75	84
		HEIGHT OF STACK IN FEET									
		125	150	175	200	225	250				
		COMMERCIAL HORSEPOWER									
90	44.18	1496	1639	1770	1893	2008	2116			80	90
96	50.27	1712	1876	2027	2167	2298	2423			86	96
102	56.75	1944	2130	2300	2459	2609	2750			91	102
108	63.62	2090	2399	2592	2771	2939	3098			98	108
114	70.88	2451	2685	2900	3100	3288	3466			101	114
120	78.54	2726	2986	3226	3448	3657	3855			107	120
132	95.03	3321	3637	3929	4200	4455	4696			117	132
144	113.10	3973	4350	4701	5026	5331	5618			128	144

NOTE: For pounds of coal burned per hour for any given size of chimney, multiply the figures in Table III by 5. For detailed discussion of theory, see Keat's Mechanical Engineers' Pocket Book, ninth edition, 1916.

The external shell is calculated for wind pressure and the weight of brick. This calculation for wind pressure involving higher mathematics will not be treated here. The lining is calculated for compression due to weight. The design, both of the chimney and its foundation, should be made by a competent engineer of experience, on account of disastrous results should a chimney fall.

SYSTEMS OF MECHANICAL DRAFT

Classification of Systems. High chimneys are costly; and it is frequently the practice to build two or three small chimneys in place of the big one, or to supplement them with some form of mechanical draft.

By means of mechanical draft, the rate of fuel combustion can be increased under favorable conditions to 60 pounds of coal per square foot of grate surface per hour. This, of course, greatly increases the capacity of the plant, but may be injurious to the boilers. There are three systems of mechanical draft in common use: (1) closed stokehold (as used in marine work); (2) closed ash pit; and (3) induced draft.

Closed Stokehold. One of the most common forms of forced draft, especially as used on warships, is obtained by closing the stokeholds and blowing a fresh supply of air into the fireroom. This gives an exceedingly good ventilation and keeps the fireroom in good condition; but its chief objection is that, when the furnace doors are opened, there is a tremendous in-flow of cold air, which tends to lower the efficiency of the boiler. If this system is employed, the bulkheads adjacent to the boiler room must be provided with double doors, forming an air lock between. By opening only one door at a time, the pressure in the fireroom is not lost. This system seems to possess but one distinct advantage, and that is coolness and, therefore, comfort for the firemen; but the disadvantage of the inrush of air to the furnaces when firing is sufficient, in some cases, to make the system questionable.

Closed Ash Pit. The essential features of forced draft by this method consist merely in closing the ash pit tight, and blowing the air directly under the grate. When the fires are cleaned, the draft, of course, must be shut off; otherwise the flames will be blown out into the fireroom. The fireroom, under this system, is likely to be hotter than by the other method; but this system would seem to be the better from a mechanical point of view.

As a variation of the ordinary closed ash-pit method of forced draft, the very important class of mechanical stokers, previously described and known as the underfeed type, must be mentioned. In all stokers of this class the success of the underfeeding principle of fuel delivery depends upon the ability of the apparatus to provide the passage of air for combustion through a very thick fuel bed. Any other method than blowing air under pressure into a wind box beneath the fuel bed, in order to overcome the high resistance of the fuel bed, would fail.

There are several patented devices in connection with the forced draft, of which the Howden and the Ellis and Eaves systems may be specially mentioned. It may be worth while to note that if fuel oil is burned, any one of these systems of forced draft will work better than with coal, for the fire can be tended without opening the firedoors.

Induced Draft. Perhaps the most common example of induced draft is to be found in the locomotive, where the exhaust steam is turned into the smokestack. The rush of this steam up the stack, by carrying a large volume of gas with it, induces a tremendous draft. Induced draft may also be obtained in stationary and marine plants by placing a blower in the chimney or stack. In marine work, of course, induced draft by exhaust steam is out of the question. The draft obtained on locomotives is frequently equivalent to a column of five or six inches of water; while a forced draft of two inches is usually considered large, except for torpedo boats, which may have as intense a draft as a locomotive.

Howden System. The Howden system of forced draft with closed ash pit has been used to a considerable extent in both mercantile and naval service. The air supplied to the ash pit is first heated by passing through a heater in the uptake. Waste gases pass through tubes; and the air, passing among them before entering the furnace, is heated to a high temperature. A consumption of 60 pounds of coal per square foot of grate is easily obtained with this system; and care must be taken that the fire is not forced too hard, as there is more danger of burning out the grate than if the air supply is not heated.

Ellis and Eaves System. Heating the air does not necessitate its being forced into the closed ash pit, for it is quite feasible to heat the air in connection with draft induced by an exhaust fan at the base of the funnel. Such is the Ellis and Eaves system. This system was first tried in the boiler shops at the works of the John Brown Company, in Sheffield, England, and was later adopted on many vessels. The Ellis and Eaves heater is fixed on top of the boilers, and is divided into two parts separated at the front by a smoke box and at the back by a funnel. The hot gases, therefore—which pass outside the tubes—have to take a somewhat circuitous course; while the passage of the air to be heated, on the contrary, takes a direct course. The distribution of air to the ash pit is similar to that of the Howden system. The advantages of this system lie in the general convenience of the induced draft and the absence of jets of hot air shooting out into the boiler room. The draft need not be shut off when stoking the fires, unless it is desired to prevent the inrush of air already referred to under the general discussion of "closed stokeholds". The air in the fireroom being of a relatively higher temperature than would obtain with closed stokeholds, and the quantity being much less, this objection has no great weight. With the Howden system it is necessary that the doors should be tight; otherwise hot air will be blown out into the fireroom. With this system a few leaks are of no consequence, and the fireroom will be somewhat cooler than with the Howden system. The objections to the Ellis and Eaves system are those inherent in any system of draft induced by a fan—a poor efficiency of the fan working in heated gases and lost work in drawing air through tortuous passages.

Steam Jets. Steam jets may be used for inducing a draft. They may be placed either in the smokestack, or below or above the grate; but in general they are not so economical as a fan used for the same purpose. In locomotives and fire engines, where the exhaust steam is at high pressure, an intense draft may be induced by exhausting this up the smokestack. In both these cases the saving of weight, due to the use of a small boiler running at high capacity, is of great practical importance; and for such purposes this arrangement is entirely satisfactory. This method of creating draft is becoming more prevalent on the continent of Europe, where many successful installations are operated.

BREECHINGS

General Items to Be Considered. The structure conveying waste or uptake boiler gases to a discharge place, as, for instance, a chimney, is called a *breeching*. These are of such shape and built of such materials as experience seems to justify. They have been and still are located in every conceivable position, both under ground and over head, and the errors in design that have been committed in their construction are in thousands of instances very costly. The following represent the main general items demanding consideration:

1. All turns should be made by long radius bends.
2. All changes in size and shape should be made gradually.
3. No cross-section dimension should ever be greater than twice as large as the dimension at right angles to it.
4. Entrance into chimneys should be made with an upward slant, so as to increase the radius of the gas travel turn at the stack as much as possible.
5. Construct them so as to prevent air infiltration.
6. Unite with other structures so outside air will not enter at the joints.
7. Provide ample air-tight cleanout facilities.
8. If underground, look to the drainage. To be effective, a breeching must be dry.
9. Do not build breechings out of brick.
10. Line steel breechings with an acid-resisting material which also resists heat transmission.
11. Support breechings free of boiler parts.
12. Depend upon individual boiler dampers and not on a breeching or stack damper when more than one boiler is connected with a stack.
13. Never provide two or more paths of travel for gases in a breeching at the same time, as by placing a chimney at each end of a breeching.
14. Do not place dampers in boiler uptakes so as to stand in the way of gases moving in the breechings when opened.
15. Try to avoid the "head-on" movement of gases from two ends of a breeching on their way to a stack.
16. If the breeching *must* be long or tortuous, be sure to allow for these things by additional chimney height to make good for the extra resistance and radiant heat loss.

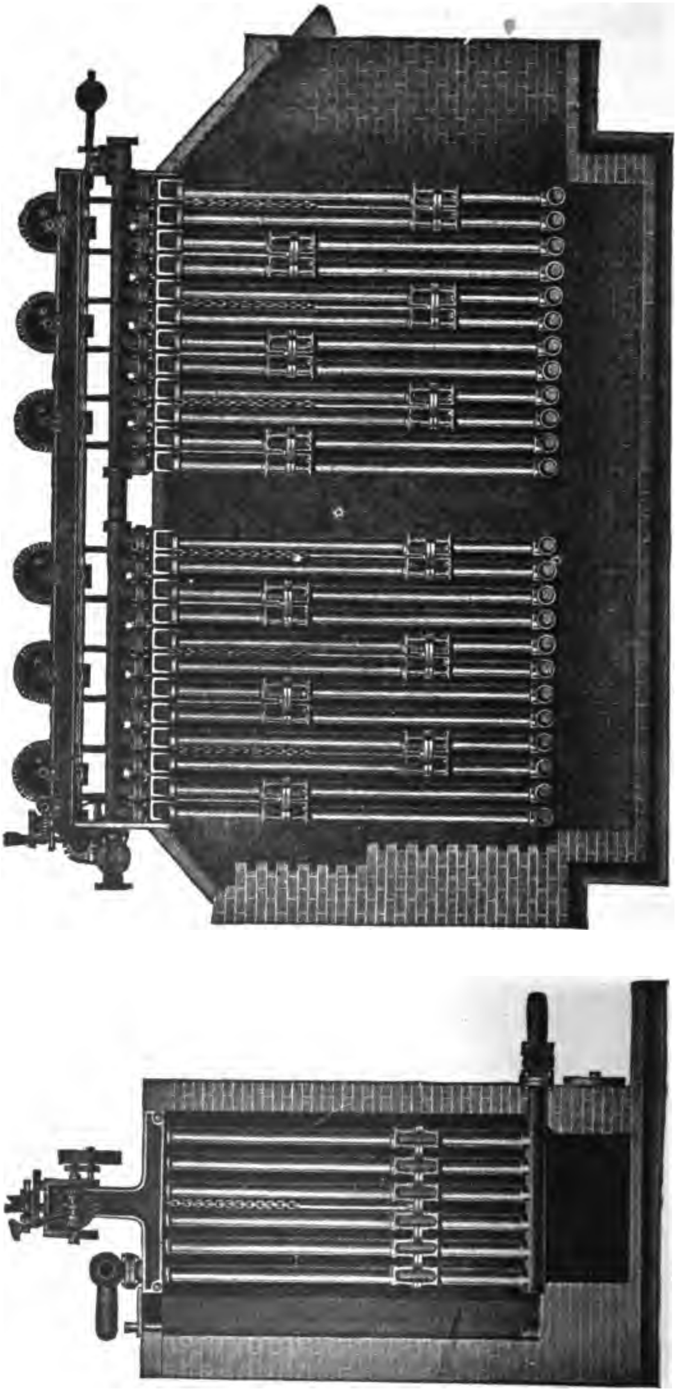


Fig. 76. Side and End Views of Green Economizer
Courtesy of Green Fuel Economizer Company, New York City

FUEL ECONOMIZERS

Many devices have been employed whereby a part of the heat may be extracted from waste gases as they pass from the boiler to the chimney. Most of these devices consist of a tubular arrangement among which the hot gases pass; but, as they are soon covered with a thick deposit of soot, they quickly become inoperative.

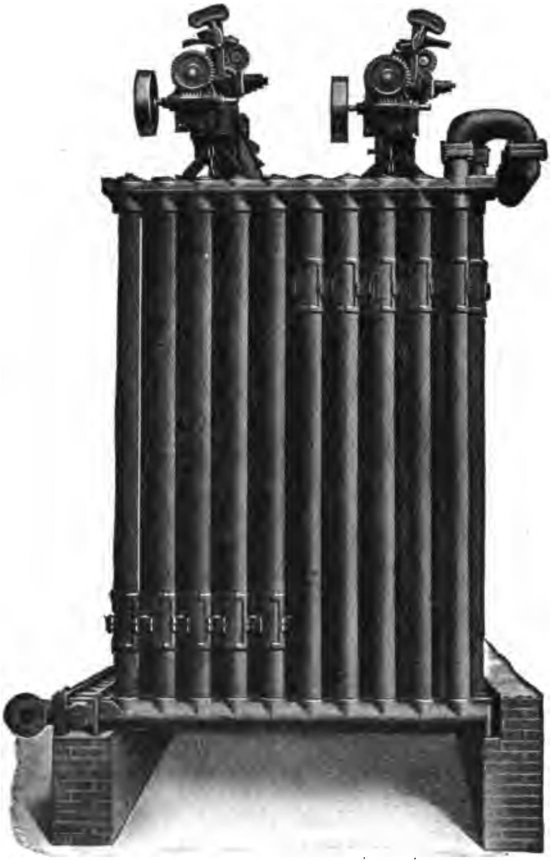


Fig. 77. Sturtevant Fuel Economizer
Courtesy of B. F. Sturtevant Company, Boston

Green Economizer. The Green economizer, Fig. 76, solves this difficulty by means of small scrapers which work up and down between the tubes. These scrapers are operated by a small engine, and keep the tubes free from soot. The feed water is pumped through these tubes on its way to the boiler and is heated. An economizer of this sort will extract considerable of the heat from the waste gases; but, by reducing the temperature of these gases, and by the extra mechanical resistance, the draft is somewhat reduced, and either the chimney must be built higher or an exhaust fan must be used. The proper installation of an economizer is a matter requiring judgment and experience, especially in the design of the flue connections and all other gas passages.

Sturtevant Fuel Economizer. In Fig. 77 is shown an economizer manufactured by the B. F. Sturtevant Company. In the illustration the inclosing walls are omitted, thus exposing to view the soot pit, pipe headers, pipes and scrapers, caps, scraper operating mechanism, etc. The casing is made either of brick or of metal-asbestos.

The special features entering into the construction of this economizer are several in number. All joints are made without the use of gaskets, dependence being placed upon metal-to-metal tapered fits. In the case of connecting the tubes to the headers the fit is obtained by hydraulically pressing the tapered ends of the tubes into the tapered holes of the manifolds. This feature does away with the necessity of removing a whole section of tubes when one tube fails, as each tube can be removed by withdrawing it upward if room is available. The tubes are placed "staggered" as a usual thing so that the heated gases more completely envelop the tubes than if they were placed in straight rows.

POWER PLANT ACCESSORIES

Importance of Properly Handling Supplies and Refuse. Distinct from the problems presented in the equipment and operation of boilers, that of providing suitable housing accommodations and facilities for the receipt, storage, moving, and weighing of fuel, and the removal, accumulation, and disposition of refuse constitutes an additional problem of great importance. In fact, the proper handling of these details demands, in most cases, the application of as much ingenuity as the subject of proper boiler setting and equipment. Unlike pure boiler and furnace design, a bad selection of conveying equipment is not reflected in the loss of efficiency in the use of fuel but is strikingly evident in the excessive cost of boiler room labor, shutdowns, and high maintenance.

The investigator of this subject cannot expect to find a complete or correct answer to his inquiries in published works of either the instructional or catalog kinds, as the variables are so numerous and their relative importance so different that it would be only by the merest chance that a proposed installation could find its counterpart in one already existing. However, specialists in the field agree upon certain fundamentals, which it is the purpose of the succeeding paragraphs to set forth.

COAL HANDLING

Systems Employed. There are two principal modes of handling coal, either of which may be adopted without regard to the size of the plant served, namely, (1) A conveying system, the elements of which consist of a coal receiving hopper (as beneath an unloading track); a short elevating conveyor discharging into a coal crusher; a conveyor feeder of an endless bucket conveyor, lifting and distributing the coal to bunkers placed above and in front of the boilers; and chutes leading the coal to stoker hoppers or to a convenient firing space on the boiler room floor. (2) A system consisting of a receiving hopper (as beneath an unloading track); a short conveyor to a coal crusher; a conveyor feeder discharging into a lifting conveyor and delivering crushed coal to a storage hopper; and a traveling larry serving stoker hoppers or the firing space on the boiler room floor.

Variations from the above descriptions are frequently provided especially in the matter of unloading coal cars by means of grab buckets and carrying the coal direct to overhead storage bins.

An excellent illustration of the first class is given by Fig. 78. In the system shown, the ashes are carried by the same conveyor which carries the coal, dumps it into the hopper *B*, from which it may be loaded directly into the same car, when empty, that brings coal to the plant. It will be noted that the system affords facilities for large storage inside the building and is especially well adapted to large plants. In the second system, distribution is made by a larry traveling the length of the boiler room, as shown in Fig. 79. The larry shown is electrically driven and includes a weighing device. When the weighing feature is desired, together with a long storage bin as in system (1), it is sometimes advantageous to employ a larry instead of chutes. By this means the storage bin may have more bottom openings than are required to serve the stoker hoppers thus affording better bin-emptying facilities than would occur with chutes alone. The larry of the type shown may be constructed with movement transverse to its main translation thus affording greater freedom in the bin construction than when chutes are used alone. It must be kept in mind that the pitch of the chutes must be ample to allow the ready flow of coal, consequently, if the horizontal distance between the furnace hoppers and the discharge pace of the bin is fixed, the vertical height of the bin above the boiler room floor must be made to fit, and *vice versa*. Necessarily, any permanent bin structure in any system of storage must be such as to permit the renewal of boiler tubes, which adds another element as to position of bunkers which enters into the problem. Where two rows of boilers face each other the larry must offer a double spout arrangement or a means for turning the larry discharging device through an angle of 180 degrees.

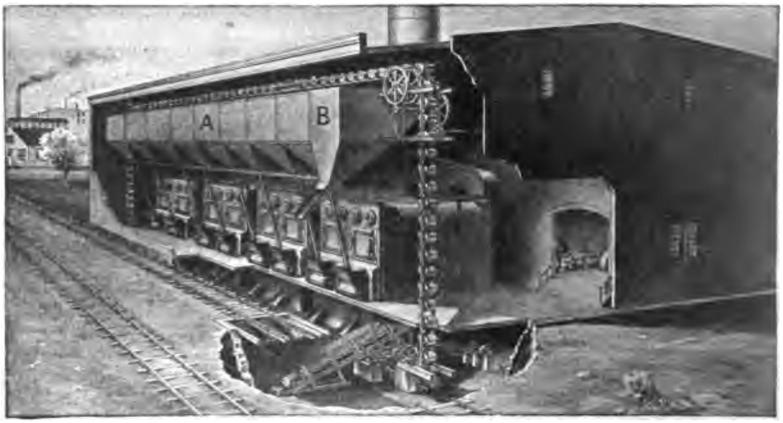


Fig. 78. Coal and Ash Handling System
Courtesy of Link Belt Machinery Company, Chicago

The larry system of conveyance overcomes one objection of the continuous bin type with chutes in that the latter cannot readily be constructed so as to completely empty themselves by gravity thus leaving an appreciable quantity of coal constantly in the bins between the chute openings. Where the coal is conveyed by a larry the storage bin need not be located in the boiler room nor need the building housing the boilers be as high as for the continuous bin type.

Chutes. Coal chutes should not be of the flaring bottom type, for it is not possible with this shape to obtain a uniform coal size distribution, the tendency being for the larger pieces to roll to the ends of the flare even if baffling is inserted in the chute. The fires are therefore unevenly charged and poor combustion is the result. The chutes should be cylindrical in section and be capable of a swinging movement along the stoker hopper length.

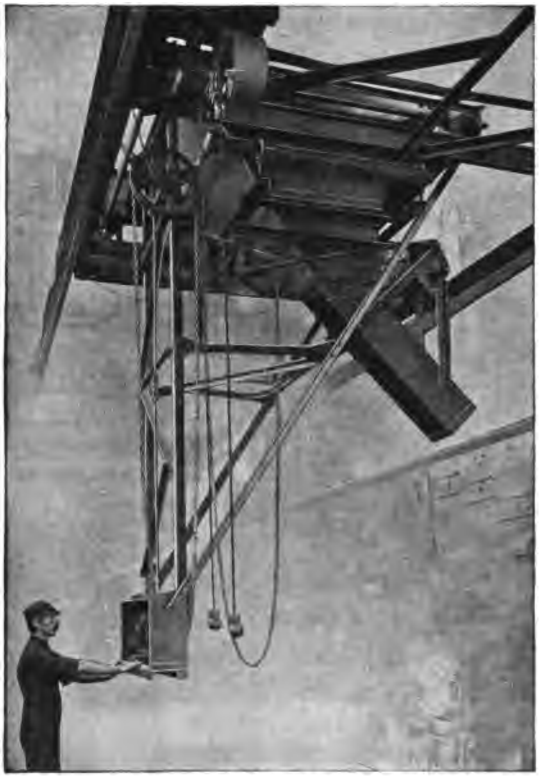


Fig. 79. Weighing Larry Electrically Driven
Courtesy of Brown Hoisting Machinery Company, Chicago

Coal Storage Bins. Coal storage bins are usually built in the form of what might be termed the continuous pattern, the bottoms constructed in a series of hopper shapes, each terminating below in a coal discharge head leading to a spout or chute. Sometimes a series of cylindrical tanks placed one beside the other takes the place of a continuous construction in which case the bottom of each tank is shaped like an inverted cone. Reinforced concrete bins having a parabolic cross-section are coming into favor because of the protection to the steel afforded by the concrete as well as other features of strength and general adaptability to space economy, etc.

ASH HANDLING

Reason for Handling Coal and Ash Separately. While the quantity of refuse material of a power plant is a great deal less than the amount of coal burned, the moving of it is attended with greater trouble and expense than that of the coal. This is due to the high abrasive quality of ash making it very destructive when used with moving machinery. On this account it has come to be recognized that ash and coal should be separately moved and the tendency is to employ a mechanical conveyor for moving coal and a system of dump cars for the moving of ash, rather than cause the destruction of a very expensive piece of machinery suitable for moving one product because a much lesser quantity of another material is conveyed by it. Again, when a conveyor is used for both materials the fact that ashes are usually wet down before charging to conveyors causes the buckets to become partially filled with a mushy mass which refuses to spill by gravity and the result that either good coal finds its way to the ash heap or ash finds its way back to the coal supply. The corrosive action of wet ashes is very great. Altogether, the problem of ash disposal is always difficult to solve whether having to do with a large plant or a small one.

Types of Systems. Recent developments have brought out two ash systems which appear to have merit within limitations though these limitations have not as yet been fully determined. Both systems use heavy chilled pipe as the conducting machinery; one employs the pneumatic, or suction, principle and the other a steam jet, or ejector, principle. The first has been in commercial existence for a number of years but has not had a wide application.

The steam jet system is a much more recent development though the application has been very marked during the last two or three years.

Pneumatic System. The pneumatic system consists of an air-tight tank connected to the intake of a power-driven fan, exhausting the air from the tank. From the top of the tank the ash line itself is led, with as few turns as possible, to the floor of the boiler room, where it passes in front of the boilers, having intakes leading into the pipes in front of each boiler. The ashes are raked into the adjacent intake tee and, owing to the vacuum set up in the tank and in the line, they are drawn rapidly into the tank by the column of air set in motion. The actual power consumption per ton of ashes is considerably higher than the ordinary mechanical methods of removing ashes. The initial cost is comparatively high and it is necessary to keep the fan and pipe line in very good condition, so as not to have a resulting drop in the vacuum produced. It is also necessary in this case to inject some water into the ash line before entering the tank in order

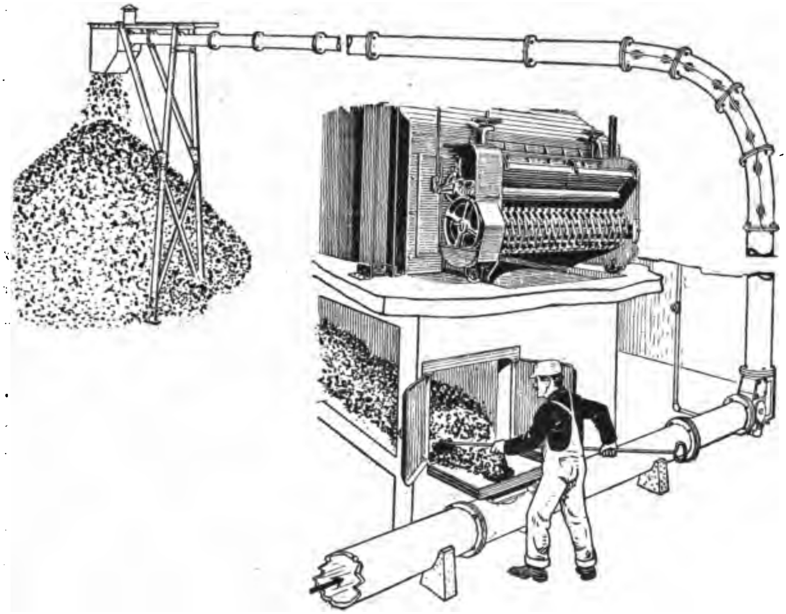


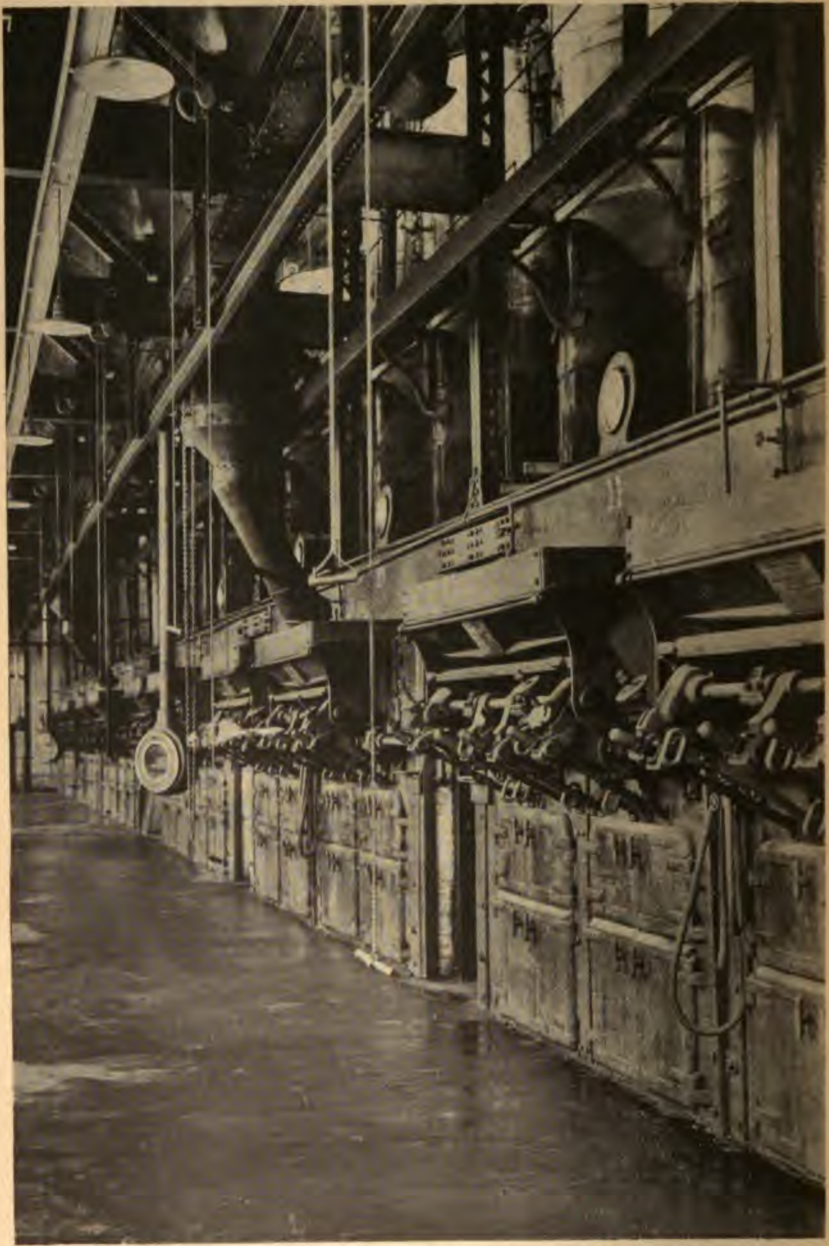
Fig. 80. Diagram of Steam Jet Ash-Handling Layout
Courtesy of American Steam Conveyor Corporation, Chicago

to kill the fire and thus eliminate the liability of explosion due to inflammable gases, produced by the combustibles, coming in contact with hot ashes as they enter the system.

Steam Jet System. The pipe and fittings employed in the steam and jet system are very much the same as employed in the pneumatic type, but instead of using an air-tight tank and a fan to produce the vacuum, this is done by steam jets inserted at one or more points along the line. The illustration, Fig. 80, shows a typical system in which the ashes are raked into the intake tees from the ash pits and deposited into a tank outside the boiler room for loading into wagons or cars as the case may be. While the power consumption per ton of ash removed is very high, the other items entering into the cost of ash removal are enough lower to make it a paying investment in a great many cases. These items are *initial cost,* including interest on the investment, *depreciation, maintenance,* and *labor.* For the same approximate amount of labor in drawing the ashes from the pit into the conveyor, the initial cost of a steam jet system is a great deal lower than any other type of ash removal conveyor, with a corresponding decrease of interest on the investment. The depreciation and maintenance are considerably smaller than would appear on the face of it. Owing to the recent improvements on the grade of metal used and the proper design of fittings for economical replacement at the points of concentrated wear, the actual maintenance per ton of ashes handled generally comes under two cents. These systems are generally made in 6-inch and 8-inch inside diameters and have a capacity of approximately 3 to 8 tons of ashes per hour. In power plants having an ash production of less than 25 tons per day, one ash system can take care of this amount quite satisfactorily. In plants where there is considerably greater production of ash and particularly those in which large clinkers comprise a considerable amount of the total, these systems are not particularly applicable. One advantage of the steam jet system consists of the dampening effect, due to the condensation of the steam itself, which eliminates any tendency for the bin to catch on fire.

In using the steam jet system, the ashes are usually drawn into a tank, but in some instances are merely deposited in a pile from which they can be removed later. In the latter case the pipe line terminates in a target box which concentrates the pile at one point. The problem of dust prevention is also quite an important one in connection with this scheme. The steam and entrained air naturally carry a good deal of ash dust in suspension, but this is frequently taken care of by the injection of a water spray in the line, effectually abating the dust nuisance. When the ashes are delivered into a tank, it is possible to eliminate a good deal of the dust by a baffle plate and a large vent, but where it is necessary to eliminate this entirely, the vent from the tank can be washed by a series of spray nozzles, thus taking all the dust out together with most of the steam. A great deal of the recent success of these systems is due to the proper study of the system as to location of steam nozzles in relation particularly to the turns and by the proper kind of metal of the greatest wear-resisting properties.

In cold climates steps must be taken to provide for the melting of ice forming masses of ash between times when blowings to or removals from the collecting bin occur.



INSTALLATION OF NEW MODEL RONEY STOKERS FOR THE GERMAN-AMERICAN SUGAR COMPANY, BAY CITY, MICHIGAN
Courtesy of Westinghouse Machine Company, E. Pittsburgh

BOILER PRACTICE

INTRODUCTION

Divisions of the Subject. In the volume devoted to Boiler Accessories are described the devices which have to do with the pressure parts of boilers used in conjunction with steam production. In the present paper the allied subjects concerned with the gas side of the heating surface will be treated. Naturally, the two divisions of the subject are very close as to their influence upon the production of steam, and it is possible that some of the material in either paper might, with as good reason, be placed in the other. However, it is well to separate the heat-generating part from the heat-absorbing part of the general subject, with the understanding that a complete treatment of the subject involves both. It will be recognized that in dealing with the subject Boiler Accessories every topic was concerned with something tangible. In the present volume the matter is less definite, and consequently more difficult to grasp. Again, the performance of a given boiler, so far as heat absorption is concerned, is a fairly definite thing and not greatly influenced by the manipulation of the pressure parts. The part here taken up is largely influenced by the way the facilities are manipulated; and, unless fully understood, there is a good likelihood that the over-all performance of the steam-generating equipment may be very unsatisfactory and uneconomical.

HEAT GENERATION

BOILER SETTINGS

Requisites. The setting for a stationary boiler consists of the foundation and as much of the furnace and flues as is external to the boiler shell. Some internally-fired boilers—the Lancashire, for instance—have flues only in the brick setting. The whole furnace, as is the case with the plain cylindrical boiler, may be within the setting. Many vertical boilers have simply a foundation; locomotive boilers have no setting; and marine boilers are usually placed on saddles which are built into the framing of the vessel.

In setting a boiler, there are three principal requisites to be kept in mind: (1) a stable support or foundation, so arranged as to allow for proper expansion of the boiler; (2) properly arranged spaces for both furnace and ash pit; and (3) a structure which will prevent loss of heat by radiation and air infiltration.

SUPPORTING STRUCTURES

Iron Supports. There are two principal methods for support: (1) by brackets riveted to the shell plates, and (2) by suspension from overhead girders by means of hooks, rings, etc. In any case, the supports should be so arranged that each shall bear its proper proportion of the load and at the same time allow for expansion. If the boiler is short, brackets are generally used, while for long boilers the girder method is the more common. If a very long cylindrical boiler is supported only at each end, the great weight between the two supports is likely to cause bending and an excessive stress on the middle plates, tension in the bottom plates, and compression in the top plates.

Foundation. The first requisite for a setting is a good foundation. If the ground is firm and favorable to a solid foundation, the excavation need be only three or four feet below the level. If it is soft, the excavation should be deeper, and the extra depth filled in with concrete; or, for very heavy work, piles may be driven.

Usually all of the setting structure below the boiler-room floor level is built of concrete. In large installations equipped with mechanical stokers, the ash pits are sometimes faced with sheet steel so that the ash will slide to its desired place during the periods between removals.

Area of Bed. In determining the area of the bed, the weight to be put on each square foot should be estimated carefully. With ordinary condition of the soil, this should not exceed 2000 pounds. For greater weights, special construction must be used.

Supporting and Enclosing Walls. The supporting and enclosing walls are built upon the foundation. The outer walls at the sides and rear are sometimes double, the space between—usually about two inches—being an air-space insulation to prevent loss of heat. Projecting bricks, which extend from the outer wall until they just touch the inner wall, allow for expansion without decreasing the strength of the inner wall. As shown in the side and end view of Fig. 1, the side walls are strengthened by buckstays or binders, which are kept in place by long bolts, secured by nuts on each end. The side view shows the supporting brackets. The front brackets rest on iron plates which are built into the walls; the rear brackets, being supported by rollers, are free to move as the shell expands. If designed for anthracite coal, the distance between the shell and the grate bars is about two feet; for volatile coals, this distance should be increased.

Furnace Walls. *Externally-Fired Boilers.* The furnace is lined with fire brick, both front and sides, including the bridge wall; sometimes portions back of the bridge, as well as the bridge itself, should thus be protected. The space between the bridge and the shell is from 6 to 14 inches, which brings the hot gases into close contact with the boiler before they enter the combustion chamber beyond, the rear and side walls being built a little higher than the top row of tubes. The fire line must not be carried above the water line; if it is, the intense heat is likely to injure the shell plates. Never expose any part of the boiler not covered with water to the flames from the furnace. The side walls are built about the same height as the rear walls. The space at the rear is bridged over and stiffened by T-irons or other suitable means.

The smoke box projects over the front end of the boiler, as shown in the side and plan view, Fig 1, and has a rectangular uptake containing a damper.

The front is usually of cast iron, with doors for firing and cleaning, and for access to the tubes. Soot, dirt, etc., are removed through the door in the brickwork at the rear.

The rear end of the boiler should be about two inches lower than the front end, so that the sediment and detached scale will tend to accumulate near the blow-off opening.

Internally-Fired Boilers. Internally-fired boilers may also be enclosed in brickwork. The setting is a support and covering, forming the side flues but not the furnace. Excess of brickwork surface in contact with the shell should be avoided, as brickwork collects moisture, which causes external corrosion.

H. T. BOILER SETTING
ON LUGS AND WITH OVERHANGING FRONT
ACCEPTABLE TO HARTFORD S. B. I. & I. CO.

A	B	C	D	E	F	G	H	I	J	K	L	M
36	14-0	7-6	18-2	6-0	30	12	8	24	10	36	30	42
42	14-0	8-0	18-2	6-3	30	12	8	30	10	42	36	48
48	15-0	8-6	20-2	7-0	36	12	8	36	12	48	42	54
54	16-0	9-0	20-2	7-3	36	14	10	42	12	54	48	60
60	16-0	9-6	20-2	7-6	36	14	10	48	12	60	54	66
66	18-0	10-0	22-2	8-1	40	16	12	54	14	66	60	72
72	18-0	10-6	22-2	8-4	40	18	13	60	14	72	66	78
78	18-0	11-0	22-2	8-7	40	19	14½	66	14	78	72	84
84	20-0	11-6	24-2	8-10	40	21	16½	72	14	84	78	90
90	20-0	12-0	24-2	9-9	48	22	17½	78	14	90	84	96

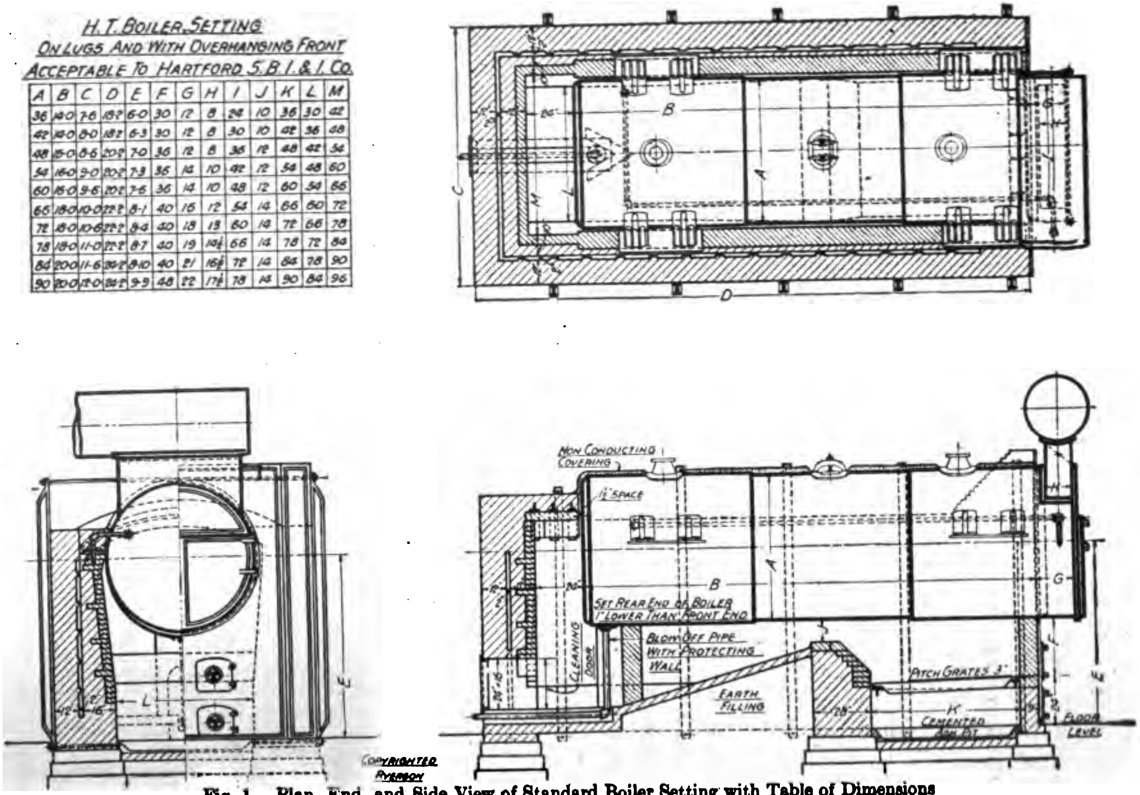


Fig. 1. Plan, End, and Side View of Standard Boiler Setting with Table of Dimensions
Courtesy of Joseph T. Ryerson and Sons, Chicago

Water-Tube Boilers. The settings of water-tube boilers differ from each other in so many ways, and also from the settings of fire-tube boilers, that it is not possible to illustrate them with any degree of completeness. The reader should consult the trade catalogues of the different manufacturers, in which the special features are illustrated. In principle, the settings of water-tube boilers must accomplish the same end that they do for horizontal tubular boilers; that is, properly support and enclose the boiler, allowing expansion space, and prevent radiation and air infiltration.

HAND-FIRED FURNACES

Furnaces and grates should be distinguished from each other in that the former are concerned mainly with providing facilities for the combustion of gas delivered by or distilled from the fuel on the grate, while the latter afford means for bearing fuel and provide means for the removal of ash. It is true that the two are not separable, but for purposes of clearness it is best to keep them separately defined. Certain adjuncts, however, are necessary to both for their successful operation. The furnace, of course, will vary in shape, size, and detail with the type of boiler and the kind of fuel; but certain essentials—such as doors, grate bars, and ash pit—are similar in all furnaces.

Supply of Air. To obtain the maximum efficiency of combustion, there should be a uniform and abundant supply of air to the under side of the grate. This is readily obtained when the boilers are externally fired, but may be somewhat restricted when they are internally fired. If smoky fuels are used, a moderate supply of air is necessary above the surface of the coal to prevent excessive smoke formation; but, as the air thus admitted is usually cold, the quantity should be small to prevent unnecessary cooling of the furnace. This air is generally supplied through a grid in the fire door.

Prevention of Radiation. Of course all possible radiation should be prevented. In the case of internally-fired boilers, this radiation is not likely to be excessive, for most of the heat would have to pass through the water in the boiler before radiating, and it is a comparatively easy matter to encase such a boiler in some sort of lagging which will prevent most of the heat from escaping. The case is somewhat different with an externally-fired boiler, where the furnace is built in a mass of brickwork below the boiler. In such a furnace a considerable amount of heat may radiate directly from the fire without coming in contact with the boiler or water at all.

Complete Combustion. To allow for complete combustion, there should be a sufficient space between the grate and the boiler. In externally-fired boilers, this space may be approximately three feet. If this distance is increased beyond proper limits, some effect of the heat will be lost; and if the distance is small, the plates are likely to be damaged and complete combustion impaired. In the internally-fired boiler, the combustion space is frequently sacrificed in order to obtain a large grate area. If the space between the grate bars and the boiler is too small to allow complete combustion, a combustion chamber must be provided immediately back of the bridge, which will permit of the further combustion of the gases. The ideal place, of course, for the combustion chamber is immediately over the grate. In locomotive boilers, the crown sheet is usually four to six feet above the grate; but such a height is manifestly impossible in marine or other internally-fired boilers, and the combustion chamber behind the bridge wall, in the Scotch boiler, partly compensates for the loss of space immediately over the grate.

The incandescent fuel and unconsumed gases should not come in contact with the cold surfaces of the boiler, if the most efficient combustion is desired. This condition is violated in internally-fired boilers, where the fire comes directly against metal having water on one side of it. If the flame is chilled by contact with cold surfaces before the gases are completely burned, a considerable amount of smoke is likely to result.

Dimensions of Grate. The grate should be of such dimensions that the fireman may be able to work it efficiently. A grate more than six feet long cannot be properly taken care of at the farther end; and if the grate is more than four feet wide, two or more fire doors should be provided. The height of the grate should be laid out with proper reference to the floor, two feet above the floor being about right. If the grate is high, it is difficult, if not impossible, to tend the fire properly. These conditions are dependent, not so much upon the boiler as upon the physical limitations of the fireman, and are eliminated by using the mechanical stoker.

Fireroom Temperature. To the above conditions may be added a suitable temperature in the fireroom. No man can tend a fire properly in excessive heat. In stationary work it is not difficult to maintain proper conditions in the fireroom; but at sea, where the supply of air is necessarily limited to what can come in through small openings, it is a different problem. The firing space on board ship is small, and the air coming through the ventilating ducts usually makes an exceedingly cold spot immediately under the duct, without producing much effect in other parts of the room.

Furnace Doors. The furnace door is usually made of cast iron, and is supplied with a circular or sliding draft plate or grid, which admits air to the top of the fire as needed. It is usually protected by a perforated cast-iron baffle plate bolted to the door casting inside, with an air space of two or three inches between. This not only protects the cast iron of the door from the direct action of the flame, but it forms a chamber for the proper distribution of the air supply, and also helps to heat it somewhat before reaching the furnace.

In many of the French torpedo boats, a patent swinging door is provided, set on horizontal hinges swinging inward. The door, of course, must be held open while the stoker is tending the fire; but in case a tube blows out, it prevents the rapid escape of steam into the fireroom. This is a matter of much more importance in the restricted fireroom commonly found on a vessel than it would be on land. Doors of this kind are gradually finding greater favor in land practice, especially in those cities where the making of excessive smoke is prohibited by ordinance.

HAND-FIRED GRATES

Size. The size of grate will depend upon the quantity of coal likely to be burned. For ordinary draft, this may be 15 pounds or upward per square foot of grate surface per hour; for forced draft, 40 to 60 pounds; and in some cases as much as 100 pounds per square foot of grate surface has been burned. If the grates are long, they are usually inclined slightly downwards, say $\frac{3}{4}$ inch to the foot, which is of great assistance in firing and makes it easier to keep fire on the farther end of the grate.*

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*The grates have an incline of a few inches, so that the bed of coal will be thicker at the rear than at the front; this allows a more even consumption of fuel, as the draft intensity at the rear is greater than in front.

Grate Bars. The grate bars are always made of cast iron. The bars are made in various forms, according to the fuel burned and the shape of the fire box. For large grates, the bars are made singly or in pairs. For smaller grates, they are made in larger groups. Grate bars should not be more than three feet in length. The length of grate can easily be a multiple of the length of these bars. The bars have distance pieces at the ends, and perhaps in the middle, to prevent distortion. They are usually 3 inches or more in depth at the middle, tapering to perhaps an inch or two at the ends; and the cross section is slightly tapered from top to bottom, so that the pattern can easily be withdrawn from the sand after casting. They are usually made a trifle shorter than the place into which they fit, to allow for expansion, 2 per cent of the length of the bar usually being sufficient for this purpose. The air spaces between the bars are usually about one-half inch in width. For burning pea coal or screenings, narrower air spaces must be used. For anthracite coal, the space may be a little larger. Bituminous coal, which readily cakes, can have considerable space between the bars—and this, indeed, is essential for a proper supply of air.

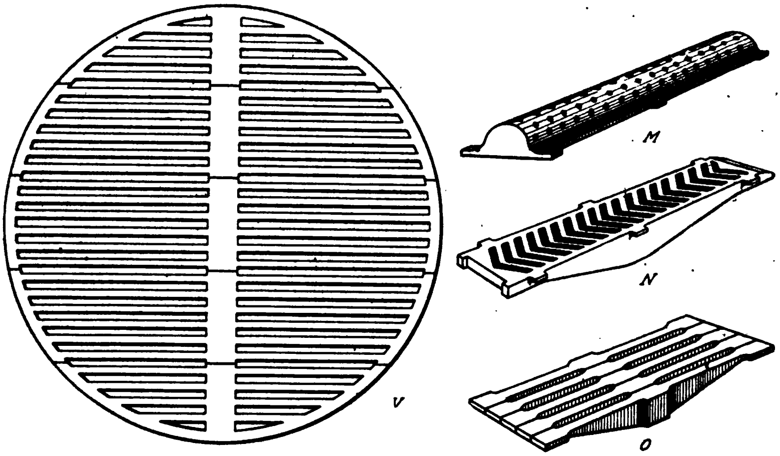


Fig. 2. Types of Grates for Boilers. *V*, Circular Grate for Vertical Boiler; *M*, Grate for Sawdust and Shavings; *N*, Herringbone Grate; *O*, Group of Grate Bars of Ordinary Form

In Fig. 2, *V* shows a circular grate, such as is placed in a vertical boiler. *M* shows the style of grate bar used in burning sawdust or shavings; *N* is what is known as the herringbone grate; and *O* is a group of bars of the ordinary form.

Grates have been made of hollow bars, through which water is caused to circulate. By this method their durability is increased. This type of grate, however, is expensive.

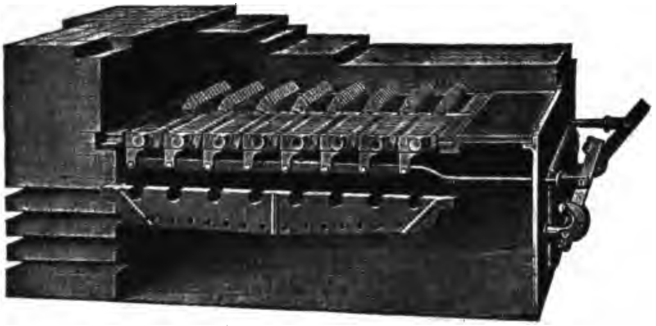
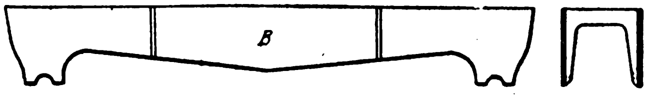


Fig. 3. Standard Rocking and Dumping Grate
Courtesy of Kelley Foundry and Machine Company, Goshen, Indiana

Rocking Grates. The labor of breaking the clinkers is considerable when the ordinary fixed grate bars are used, and, to economize this labor, various forms of rocking grates or shaking grates



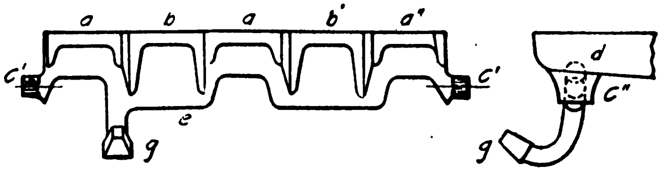


Fig. 4. Rocking Grate Consisting of Alternate Bars with Ends of Different Depths Resting on Crankshaft, Oscillated by a Lever

have been devised. In locomotives, rocking grates are essential; and, since the rate of combustion is high, the fire must always be kept in good condition; and the grate, being below the cab floor, cannot easily be reached.

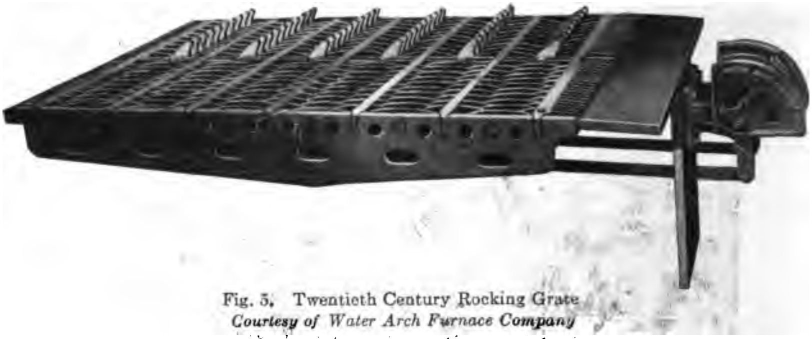


Fig. 5. Twentieth Century Rocking Grate
Courtesy of Water Arch Furnace Company

Types. Fig. 3 shows the Kelley Standard rocking grate. Each bar is made up of a number of separate leaves, which can be removed and replaced without renewing the whole bar. When the bar is moved back and forth by means of a lever outside the brickwork, the leaves oscillate through a small angle and break up the clinkers.

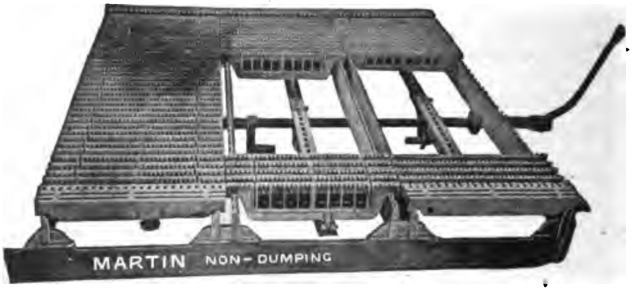


Fig. 6. Martin Shaking Grate
Courtesy of Martin Grate Company, Chicago

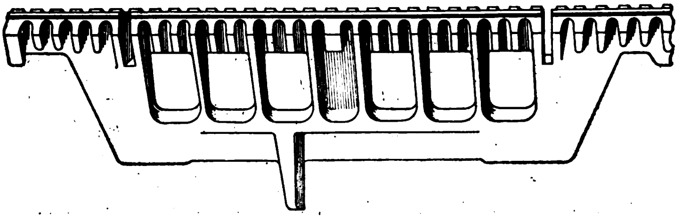


Fig. 7. Single Bar of Martin Grate

Another form of bar, shown in Fig. 4, has proved very satisfactory. *A* and *B* are two bars, the ends of which are of different depths. These rest at each end on a crankshaft *C*. As this is oscillated by the lever *G*, the alternate bars move up and down, and the clinkers are shaken out.

Still another example of rocking grate is shown in Fig. 5. In this grate the rocking and stationary bars alternate; when the rocking lever is removed from its socket, the grate must be in its neutral position, thus insuring against burning off grate fingers. It is known as the Twentieth Century rocking grate.

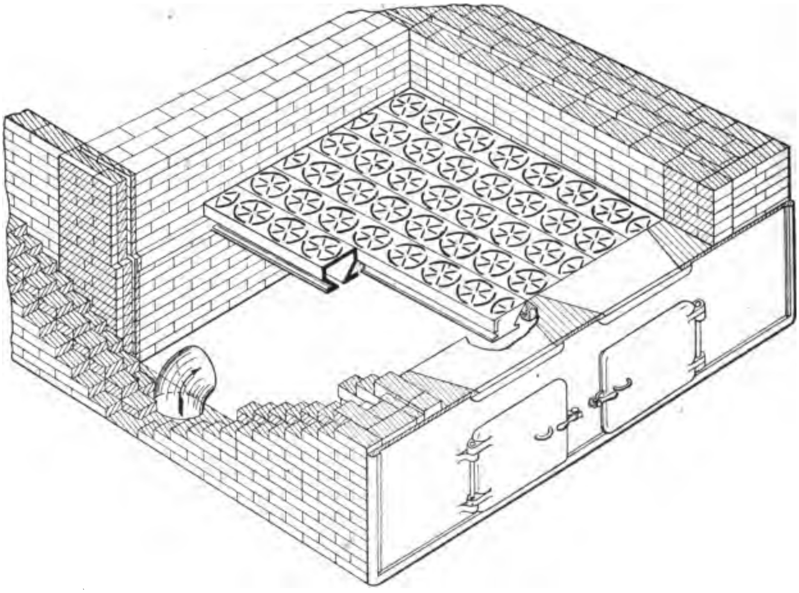


Fig. 8. Sectional View of a Furnace Showing Nicholson Grate Bars Assembled
Courtesy of Improved Combustion Company, Chicago

Dumping Devices. Opinions differ as to whether or not the grate should have a dumping feature. Consequently, there are all types in the complete list—those going to extremes in providing dumping facilities; and those having shaking grates which, instead of dumping, depend upon frequent shaking to remove the ash before it has time to fuse into clinker. Figs. 6 and 7 illustrate the Martin grate, clearly showing that the lift of the grate can only be very small.

Forced-Draft Arrangement. For the burning of some kinds of fuel, and sometimes for the more rapid burning of fuel, forced-draft equipment is provided with hand-fired grates. Such an arrangement is illustrated in Fig. 8, which is known as the Nicholson furnace. The air is delivered beneath the grate under pressure and is discharged through slots in the bars, Fig. 9, which bear the fuel. The slots are cast at a slant, so that the air does not blow vertically; while the bars are set close together and a seal of cement is placed between adjoining pairs, so that the air is forced to pass through the slots instead of between the bars. There are many forms of hand-fired grates in use applying the principle of forced draft, but the one shown is typical of all except for the grate-bar details.

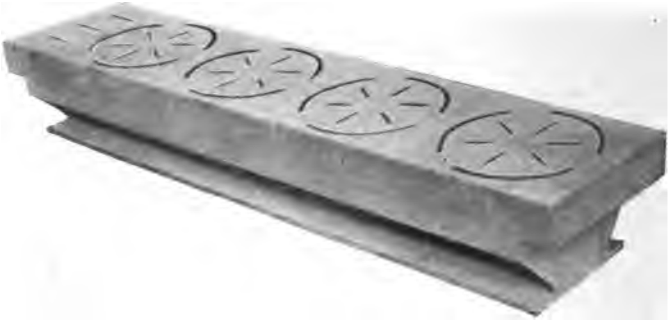


Fig. 9. View of Single Nicholson Grate Bar
Courtesy of Improved Combustion Company, Chicago

FIRING BY HAND

Starting the Fire. The fireman should first ascertain the water level. As the gage glass is not always reliable, on account of impurities, foam, etc., the gage cocks should be tried. In a battery of boilers, the gage cocks of each should be opened, for the water may not stand at the same level in each. The safety valve should be raised slightly from its seat. If the fire has been banked over night, open the dampers, and remove the ashes and clinkers from the grate. In case the fire has been allowed to go out, a new one may be started if the gage glass shows the proper amount of water and the valves work well.

If anthracite coal is used, first throw a thin layer of coal all over the grate, then place a piece of wood across the mouth of the furnace just inside the door and lay other pieces of wood at right angles to the crosspiece with the ends resting on it. This allows a space under the wood for air. Now throw on coal until the wood is covered.

The fire may be started with oily cotton waste, shavings, or any combustible material.

Keep the furnace door open and the damper almost closed until the wood is burning freely, which causes the flame to pass over and through the coal and to ignite it. The fire is then spread or pushed back evenly over the furnace bars; the furnace door is closed, and the ash-pit door opened; more coal is added when necessary. If bituminous coal is used the same process is serviceable.

The fire at the start should be slow, to cause gradual, uniform heating of the water and various parts of the boiler. If steam is raised too rapidly, enormous stresses are set up, due to unequal expansion, thereby causing leakage at seams, and perhaps rupture.

If the boiler is of the water-tube type, steam may be raised more rapidly, because the amount of water is less and the seams are usually placed at some distance from the intense heat of the fire.

Methods of Adding Fuel. The fire being started, the method of adding coal depends upon the fireman, the kind of coal, the type of boiler, and the rate of combustion. There are three general methods of firing—spreading, alternate or side firing, and coking.

Spreading. Spreading is accomplished by placing small quantities of coal uniformly over the entire surface of the grate at short intervals. By this method, the coal is thrown just where it is wanted and then not disturbed. Good results are obtained from this method, since the fire can be kept in the right condition at all times, if the coal is of the right sort. During the operation of firing, the door should be kept open as little as possible, or the fire will be cooled by the entrance of cold air. For a short time, while the coal is giving off gas, the draft plate of the furnace door should be opened, in order that sufficient air may be admitted above the coal to burn the gas. The spreading method is especially effective for high rates of combustion.

Alternate or Side Firing. When the alternate or side-firing method is used, coal is spread so as to cover one side of the fire completely at one firing, leaving the other side bright. At the next firing, the bright side is covered. The gases given off by the fresh coal are assisted in burning by the hot gases coming from the incandescent coal. This method is superior to spreading, because the entire furnace is not cooled off by the addition of fresh fuel.

Side firing is very advantageous when two furnaces lead to a common combustion chamber. The furnaces are fired at regular intervals with moderate charges of coal, and the draft plates in the firing doors are opened while the coal is giving off gas.

The two systems described above are also adapted to anthracite coal, since it burns with comparatively little smoke.

Coking. With semibituminous coal, which is volatile and burns with considerable smoke, the coking method is used. The coal is piled on the grate just inside the door, and allowed to coke from 15 to 30 minutes. During this time, the hydrocarbons are driven off and burned while passing over the more intense fuel bed behind. In order to accomplish this fully, air must be admitted in small quantities above the grate through the draft plates of the furnace doors. The coke is next pushed backward over the fire, and a new supply placed on the front of the grate. It is very important that the air admitted over the fire be enough but not excessive, for, in the latter case, economy is reduced, the furnace cools somewhat, and the rate of evaporation is reduced. This last objection is not serious unless the boiler must be worked to its maximum capacity in order to furnish the required amount of steam. The available draft over the fire is the main factor determining the rate at which a given fuel can be burned, while the temperature of the furnace above the grate also has an influence.

Thickness of Fuel Bed. The thickness of the fuel bed can be determined only by experiment. As a general thing, the thickness is changed according to the steam requirements, for the rate of combustion is large or small as the amount of air passing through the grate and fuel bed is large or small. By thickening the fuel bed, and consequently the fuel-bed resistance, the amount of air is reduced, and *vice versa.* The economical thickness at which to burn fuel is an entirely different matter than the amount which *can* be burned. In general, speaking of bituminous and semibituminous coals only, the better coking coals are best burned with thick fires and the free-burning non-coking coals with thin fires. A fire fifteen inches thick is considered about right for a good coking coal, while a fire five inches thick is about right for a free-burning bituminous coal. Should the rate of combustion, using a desirable thickness of fuel bed, be wrong in the production of the desired amount of steam, the grate area should be changed so that both conditions are approximately right. The secret of success in the burning of fuel is one concerned almost altogether with the selection of a proper grate area within the possibilities presented by the available draft over the fire for the fuel to be burned.

After finding from experiment the best thickness for the bed, keep it at that thickness. Always keep the bed of uniform thickness, and never let the fire burn holes in the bed, and *do not let the rear of the grate become bare.* If a larger amount of steam is required, fire smaller quantities at more frequent intervals. Do not fire a large amount of coal, and then wait for the pressure to rise. The firing of fresh coal chills the furnace and temporarily retards combustion. The coal should be fired in small quantities and as quickly as possible. Keep the fire free from ashes and clinkers, but do not clean the fires oftener than is necessary.

Cleaning the Fire. *Tools.* Four tools are used for cleaning the fire—the slice bar, the prick bar, the clinker hook—sometimes called the devil's claw—and the hoe or rake.

The slice bar is a long, straight bar, with the end flattened. It is used to break up clinkers by thrusting it between the grate and the fire. It is also used to break up caking coal. The prick bar is similar to the slice bar, except that the end is bent at right angles like a hook. To remove ashes, the prick bar is run along from underneath up between the grate bars. This bar is often made with detachable hook, so that the end may be replaced when burned off. The clinker hook, or devil's claw, is used to haul the fire forward. The hoe, or rake, is used to draw out cinders, to haul the fire forward, to level the fuel bed, etc.

Cleaning Methods. In cleaning the fire, the fireman first looks to the water and steam. There should be enough water and sufficient steam pressure to last during cleaning. Then he breaks up the clinkers with the slice bar, and removes the ashes with the prick bar. If necessary, he pushes the fire to the rear, thoroughly cleans the front of the grate bars, and then hauls it forward and cleans the back of the furnace bars. Some firemen clean one side at a time, instead of first the front and then the rear. The fire should be allowed to burn down before cleaning, but sufficient fuel should be left to start the fire quickly. Before cleaning, partly close the dampers, so that the amount of cold air admitted will be small. For this reason, and to prevent loss of pressure, clean as rapidly as possible.

When the demand for steam requires the most that can be made at all times, and more than one boiler is in service, one portion of the grate of one boiler is cleaned first; a similar portion of the adjoining grate next; and so on down the whole line before returning to the first fire to finish. Skill is required in carrying out such a program.

Banking the Fire. Banking the fire depends upon the condition of the fire, the fireman himself, and the length of time it is to remain banked. First clean the fire and place all the coal in a small space at the bridge; then cover it with fresh coal to a depth depending on the length of time the fire is to remain banked. Then almost close the dampers and open the firing doors slightly. Some firemen cover the front of the grate bars with ashes.

To start from a banked fire, first examine the condition of the water level, steam pressure, safety valves, etc. Then clean the fire with the slice bar and shake the ashes down with the prick bar. After spreading the live coal evenly over the grate, cover with a thin layer of green coal and open the dampers.

SPECIAL HAND-FIRED FURNACES

There are a great many forms of settings for stationary boilers different from the standards manufactured by the boiler builders, and only a few can be touched upon here. From a plain hand-fired setting—where no special provisions for combustion are made—to the most elaborate mechanical stokers, there is an endless variety of furnaces.

Horizontal Tubular Boilers. For horizontal tubular boilers it is usual to retain hand firing because the size of the unit is not large enough to justify the use of a more efficient, and possibly more complicated, firing arrangement. The men who are hired to operate horizontal tubular boilers are frequently not as well informed and as capable as those who operate larger units; and this has something to do with the matter also.

Steam Jets, Fire-Brick Arches, etc. Where the attempt is made to improve the combustion conditions under horizontal tubular boilers, the first thought is usually to supply steam jets, either manually or automatically operated; fire-brick arches and piers are next added and, when further progress is wanted, one of the special furnaces described later may be adopted. In principle, the advantages of the several forms of fire-brick furnace constructions are identical. They all aim to provide a chamber in which the mixture of unburned gas with air can be carried on for a sufficient length of time to permit the complete combustion of the gas evolved from the fuel bed. During the time the combustion process is taking place, it is aimed to prevent contact between partly burned gas and the boiler-heating surface lest the temperature of the burning gas be reduced to a point not favorable to combustion.

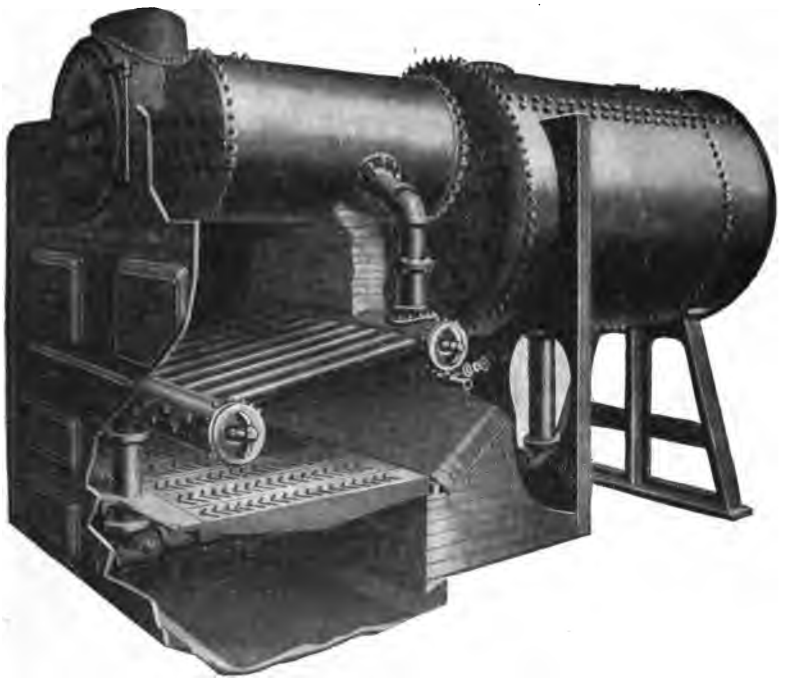


Fig. 10. Down-Draft Grate Fitted to Fire-Tube Boiler
Courtesy of Hawley Down-Draft Furnace Company, Easton, Pennsylvania

Semi-Automatic Furnaces. In order to overcome to some degree the human operating element in firing, furnace constructions are sold which are more or less independent of the manner in which the fireman supplies the coal or other fuel to the chamber or hopper leading to the furnace or grate.

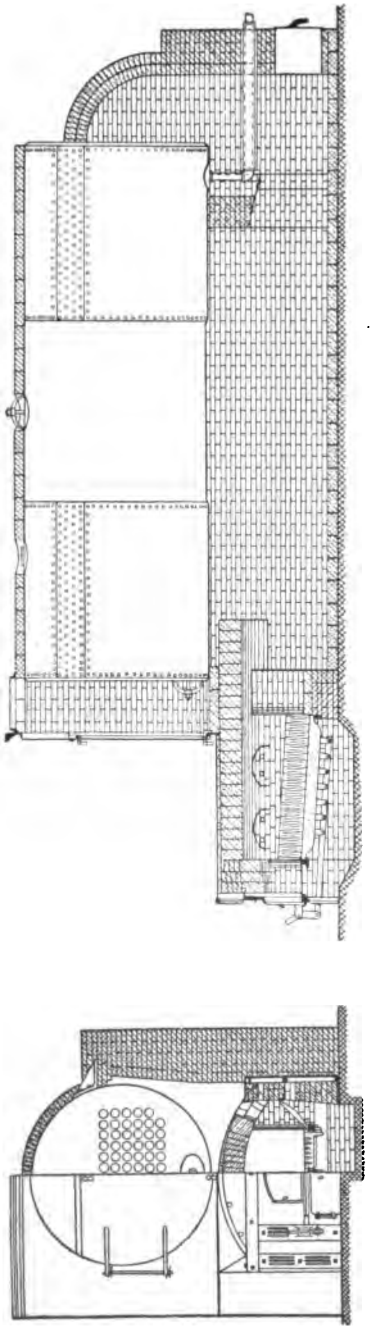


Fig. 11. Burke Inclined Furnace Attached to Horizontal Tubular Boiler
Courtesy of Burke Furnace Company, Chicago

Down-Draft Furnaces. In order to increase economy and capacity, or to prevent smoke, a down-draft furnace is sometimes used. In this type of furnace, there are two grates, one a foot or more above the other. Fresh coal is fed to the upper grate, and, as it becomes partly consumed, falls through to the grate below, where the combustion is continued. The draft is downward through the upper grate, and upward through the lower, because the connection to the chimney is from the space between the grates. The volatile gases are carried down through the bed on the upper grate, and are burned in the space below it, where they meet the hot air drawn upward from the lower grate. Most of the air for combustion enters the door at the upper grate.

In the furnace made by the Hawley Down-Draft Boiler Company, the grates are formed of a series of water tubes opening at the ends into steel drums, which are connected with the boiler. Fig. 10 shows this furnace attached to a horizontal tubular boiler. It may be applied to both tubular and

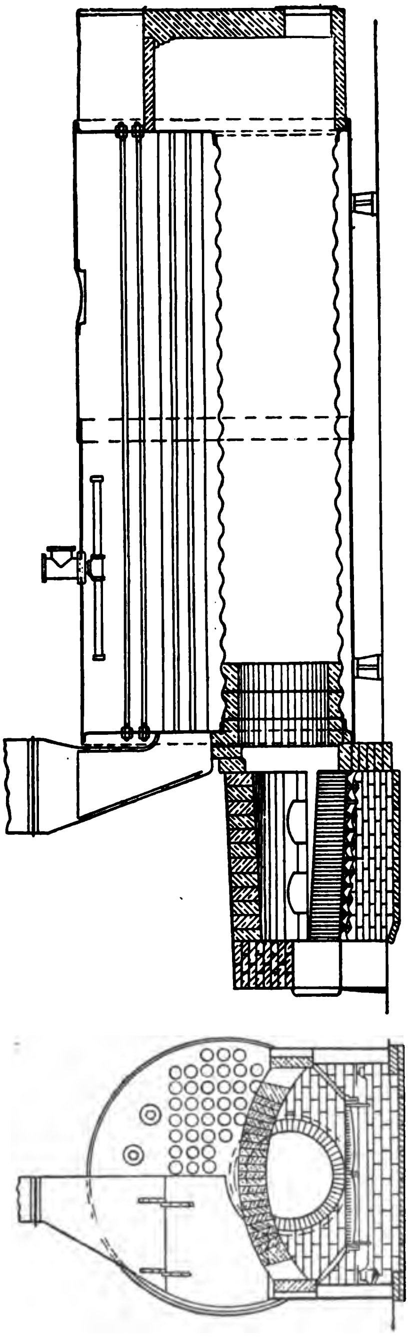


Fig. 12. Burke Inclined Furnace Attached to Scotch Boiler
Courtesy of Burke Furnace Company, Chicago

water-tube boilers with good results. It is claimed that this attachment insures complete combustion, small amount of ashes on account of the second grate, good water circulation, and increased economy.

Gravity Feed Furnaces. The difficulty in getting firemen to carry out good firing methods has brought about the construction of a class of furnaces into which the fuel is charged by gravity. The Burke gravity feed furnace is illustrated in Fig. 11, which shows this furnace applied to a horizontal tubular boiler. The fuel is placed upon the furnace arch and allowed to enter the furnace by running down through the holes or "pockets" on each side of the grate. By keeping the hopper (not shown in the illustration) filled as the fuel burns away in the furnace, additional new fuel finds its way into the furnace.

In Fig. 12 is shown the same furnace applied to a Scotch boiler. This is particularly effective as it tends to overcome some of the inherent defects of an internally-fired Scotch boiler.

Oil-Burning Furnaces. *Requirements.* In some localities oil is the fuel most readily available, and since, even in a crude state, it has a heat value somewhat above that of a like weight of coal, it is quite essential to make provisions for its use. In general, the oil is sprayed into the furnace chamber by special means described hereafter. Of great importance, however, is the matter of the chamber in which the oil is burned. It is especially necessary to provide a chamber sufficiently large so that the flame may reach its natural limits without encountering boiler-heating surface.

Advantages. Oil has many advantages as a boiler fuel. It is clean, gives a uniform heat, is economical, and requires much less attention than coal. There are no ashes to handle, and one man can easily tend two or three times as many furnaces as he could if burning coal. The fire can be started and stopped instantly; and the supply of air can be so regulated that, unless burners and combustion chamber are overtaxed, there will be almost no smoke.

Method of Action. Oil fuel is fed into the furnace through a sprayer formed, in some cases, of two concentric conical tubes. Compressed air or steam entering through the one tube draws the oil through the other, on the principle of the atomizer, and throws it into the furnace in a fine spray. For marine work, compressed air should be used, as the loss of steam for this purpose would be a matter of considerable consequence. Steam, however, is sometimes used in marine work, in which case the vessel must be equipped with an evaporator to make up the steam thus lost. On land, where fresh water is plentiful, steam is usually preferred and is less expensive than air.

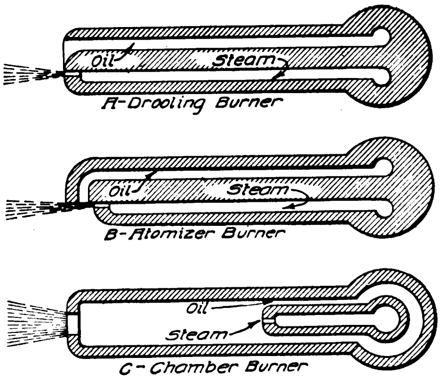


Fig. 13. Types of Atomizers for Liquid Fuel

Types of Sprayers. Several types of atomizers are shown in Fig. 13. The use of the oil as a fuel can be readily controlled by the simple manipulation of a valve; and if the fire is once regulated to produce the required heat, it can be kept at that point with very little care. The fire can be started with slight trouble, and can be extinguished instantly. The evaporative capacity of oil is much greater than that of coal; and on the Pacific Coast, where oil can be readily obtained, it is a much more economical fuel. If burned properly, without too heavy an air blast, there should be no production of smoke. A considerable saving may be effected in the fireroom force, one man being able to operate several burners. There is, of course, danger from explosion, on account of the vapor which rises from the fuel; but if the fuel tank is thoroughly ventilated, there should be little danger from this source.

Oil fuel may be used to advantage in what is called mixed firing; that is, the oil may be sprayed on to the bed of burning coal. This has been condemned by many engineers, but it has nevertheless gained considerable headway and, under proper conditions, has given satisfactory results. It is beyond the scope of this work to go minutely into the subject of oil fuel; but for further information the student is referred to the reports of the Oil Fuel Boards of the United States Navy and of the British Admiralty.

MECHANICAL STOKERS

Function. A mechanical stoker is a device having two functions; namely, to introduce fuel into a furnace, and to remove the resulting refuse. If the stoker introduces the fuel at a uniform rate, and removes the refuse at the rate at which it is formed, without manual assistance, it accomplishes every possible service that can be expected of it. The facilities which must be provided in addition for the combustion of the gases rising from the fuel bed are properly known as furnaces. It is true, however, that some forms of stokers lend themselves by their construction and shape to good furnace construction, while others do not. This feature of the subject will become clearer when the several forms of stokers are described.

Classification. There are five principal types of mechanical stokers. They are:

(1) Mechanical fuel spreaders or firemen
(2) Traveling grates
(3) Inclined grates
(4) Underfeed stokers
(5) Combinations of the above

The devices of the first group accomplish little beyond that performed by a careful fireman except that the fuel may be more uniformly charged, though it is likely that the fuel bed may not be so evenly charged as by a competent fireman. This class of stoker fails to remove the ash and refuse from the grate, and in this particular is quite deficient.

All of the other types mentioned aim to introduce the fuel steadily by bringing it into the hottest zones of the furnace at a uniform rate. The result is that the volatile gases are driven from the fuel at a nearly uniform rate, and consequently the furnace can be constructed of such a shape and size as to provide an adequate chamber in which to facilitate combustion.

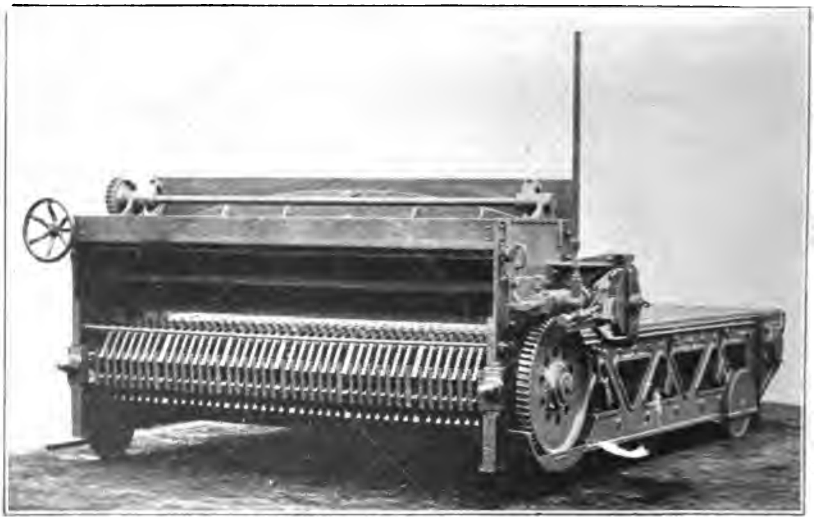


Fig. 14. Chain Grate Mechanical Stoker
Courtesy of Babcock and Wilcox Company, New York City

Fuel Used Determines Type of Stoker. The character of fuel burned should determine the kind of stoker selected, as some forms are very efficient with one grade of fuel and wholly inefficient with other grades. The leading coal characteristic needing consideration is its ability to coke or cake, which, of course, is largely influenced by the percentage of refuse, and its kind, in the natural fuel. To illustrate the point just made, attention need only be called to the fact that a traveling grate without special facilities for handling coked fuel is not at all successfully used with the high-grade coking coals mined in Virginia and Pennsylvania. This type of stoker is especially adapted for use with the free-burning, highly volatile coals found in Illinois and Iowa. On the other hand, some types of stokers require, for their successful use, the coal to have caking qualities. As an example, the Murphy double-inclined grate may be mentioned.

Traveling Grate Stokers. Among the various makes of traveling grates, probably the best known are the Babcock and Wilcox, the Green, the Playford, the La Clede, and the Illinois. These all operate on the same principle, differing only in details of construction.

The Babcock and Wilcox chain grate which is typical of the rest, Fig. 14, consists of an endless chain of short grate bars or links moving over sprocket wheels at the front and rear end. These sprocket wheels are driven by a mechanism consisting of a gear train actuated by pawls and a ratchet, the arms carrying the latter being given a reciprocating motion by a rod and eccentric mounted on a shaft. This shaft may be operated by any type of motor or engine, and the speed of the grate is regulated by varying the stroke of the arm carrying the pawls. The fuel is fed to the traveling grate through a hopper, which extends the full width of the grate and is mounted on the front end of the frame. The depth of the layer is regulated by a gate in the hopper, which can be raised or lowered. The coal is ignited at the front end and carried slowly toward the rear, the speed of the grate and the thickness of the fire being so regulated that the fuel shall be completely burned by the time it reaches the back end, nothing but ashes being discharged into the pit. A flat firebrick arch in the front end aids combustion by igniting the fresh fuel as it enters and keeping up the temperature of the burning volatile gases. The entire hopper, grate, and driving mechanism are mounted on a truck running on rails and thus may be withdrawn from beneath the boiler when repairs to grate or furnace are necessary.

Inclined Grate Stokers. *Front Feed.* Some of the types of this form of stoker are the Roney, Wilkinson, and Acme. The Roney stoker, Fig. 15, consists of a hopper for receiving the coal, a set of rocking stepped grates inclined at an angle from the horizontal, and a dumping grate at the bottom of the incline for receiving and discharging ash and clinkers. This grate is divided into several sections for convenience in handling. The coal is fed to the inclined grates from the hopper by a reciprocating pusher. The grate bars rock through an angle of 30 degrees, assuming alternately the stepped and inclined position. These also receive their motion from the agitator, which receives its motion from an eccentric on a shaft attached to the stoker front under the hopper. The range of motion of the pusher is regulated by the feed wheel and the range of motion of the grate bars is regulated by the position of the nuts on the connecting rod. Each grate bar consists of two parts: the vertical web carrying trunnions at each end; and the horizontal part, or fuel plate, which is detachable. A flat fire-brick arch is sprung across the front of the furnace. This ignites the fresh fuel as it enters and aids in keeping up the temperature of the volatile gases until they are burned.

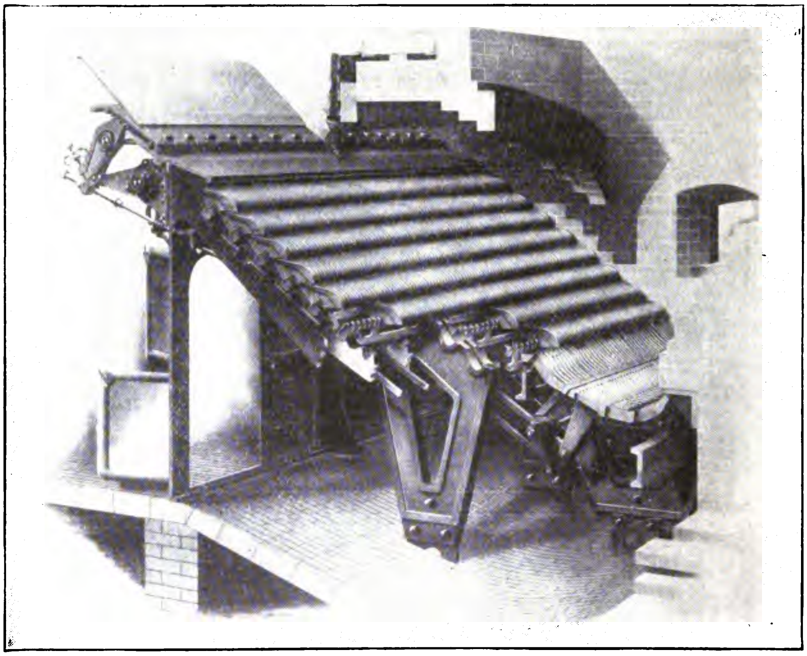


Fig. 15. Roney Step-Grate Mechanical Stoker
Courtesy of Westinghouse Machine Company

The Wilkinson stoker, Fig. 16, consists of a hopper, a set of inclined grate bars having every other bar movable, and the operating mechanism. When in operation there is a constant sawing action of the grate bars, causing the fuel to be fed forward continuously. The grate bars are hollow and have a succession of steps cast on them throughout their length. Through the rise of each step is an opening of about $\frac{1}{3}$ inch by 3 inches. A small steam jet

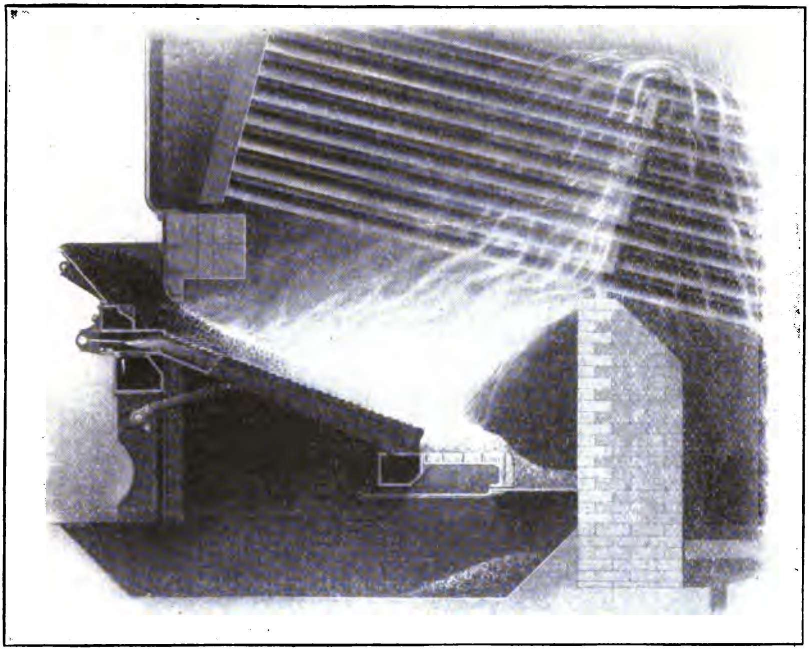


Fig. 16. Wilkinson Step-Grate Mechanical Stoker
Courtesy of Wilkinson Manufacturing Company

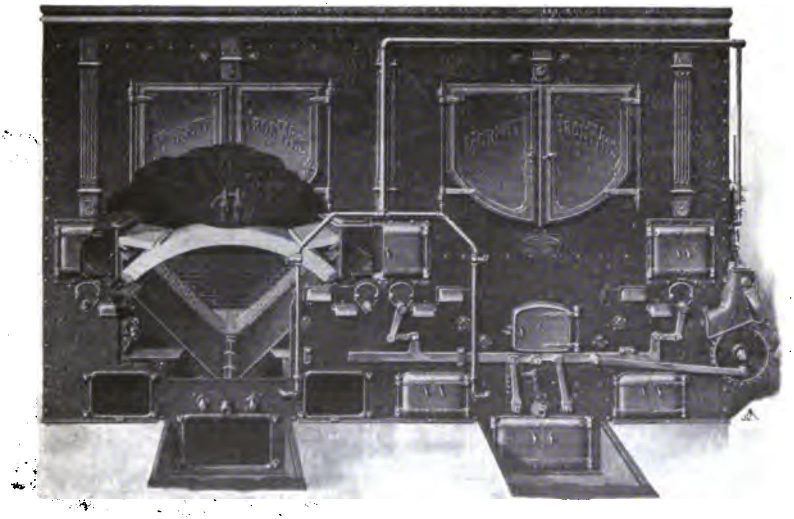


Fig. 17. Front View Murphy Mechanical Stoker
Courtesy of Murphy Iron Works

with about $\frac{1}{16}$-inch opening is introduced into the end of each grate bar, and this induces an air supply through the openings in the steps. The motor for operating these stokers may be either steam or electric and is attached to the front of the stoker.

Side Feed. The best known stokers of this type are the Murphy, the Detroit, and the Model. The Murphy stoker, Figs. 17 and 18, consists of two hoppers, or magazines, one on each side of the furnace, two sets of grates inclined downward from the sides of the furnace, and the operating mechanism. Coal is introduced into the hopper and falls upon the coking plate, Fig. 17. Here the reciprocating pushers feed the coal out upon the inclined grate bars. Alternate grate bars are movable and pivoted at the upper ends. The lower ends are caused to move up and down by a rocker shaft, thus causing the required forward feeding of the coal. A device, Fig. 18, consisting of a hollow bar provided with teeth, is placed at

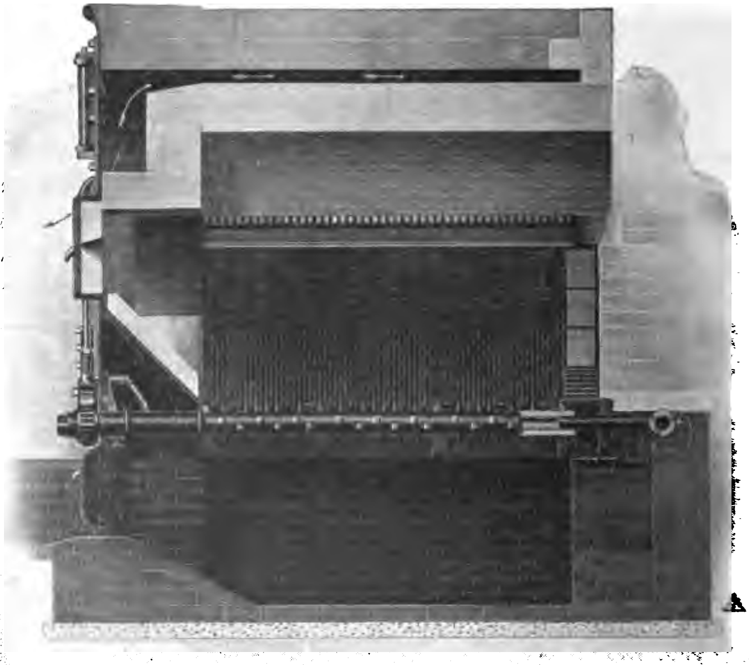


Fig. 18. Side Section Murphy Mechanical Stoker
Courtesy of Murphy Iron Works

the lower ends of the grates, and serves to grind up clinkers and ash. Air is supplied through flues passing under the coking plate, and the speed of the grate bars and pusher is regulated to suit the desired rate of combustion. A small motor or engine operates the driving mechanism of the stoker.

Underfeed Stokers. Among the various stokers of this class will be found the Jones, the American, the Taylor, the Riley, and the Westinghouse.

Jones Type. The Jones stoker, shown in Fig. 19, consists of a steam-actuated ram and a hopper outside of the furnace and a retort or fuel magazine and auxiliary ram or pusher rod within. Fuel is forced underneath the fire by the ram and its auxiliary, and this forces the incandescent fuel and ash back and up over the sides of the retort upon the dead plates. As there is no ash pit, the ashes are raked from the dead plate by hand. Air supplied by a blower is admitted through openings in heavy cast-iron tuyère blocks placed on either side of the retort. These are at a point above the green fuel in the retort but below the fire, and the air moving upward keeps the retort cool.

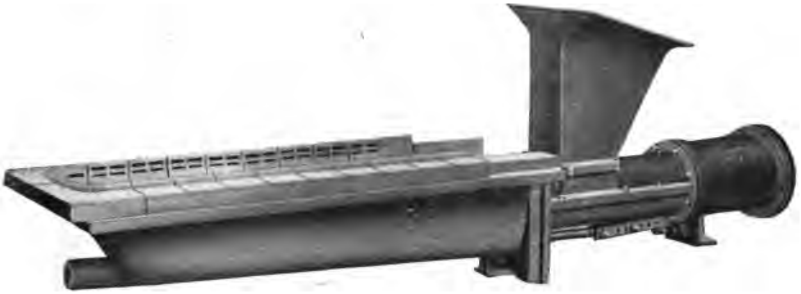


Fig. 19. Jones Underfeed Mechanical Stoker
Courtesy of Underfeed Stoker Company of America

American Type. The American Underfeed Stoker is illustrated in the two sections given by Figs. 20 and 21. Its principle of fuel introduction is practically identical with the Jones, just described. The device differs from the Jones in that side grates are added both for the further supply of air, and consequent greater range of combustion, and in the facilities for the removal of refuse by means of dumping grates on the sides of the grate. In both of these particulars the American comes more nearly fulfilling the functions of a stoker than a retort stoker requiring cleaning by hand altogether.

In this stoker the attempt is also made to introduce preheated air by taking air which has previously passed through the grate bars as the supply for the grates bordering the retort.

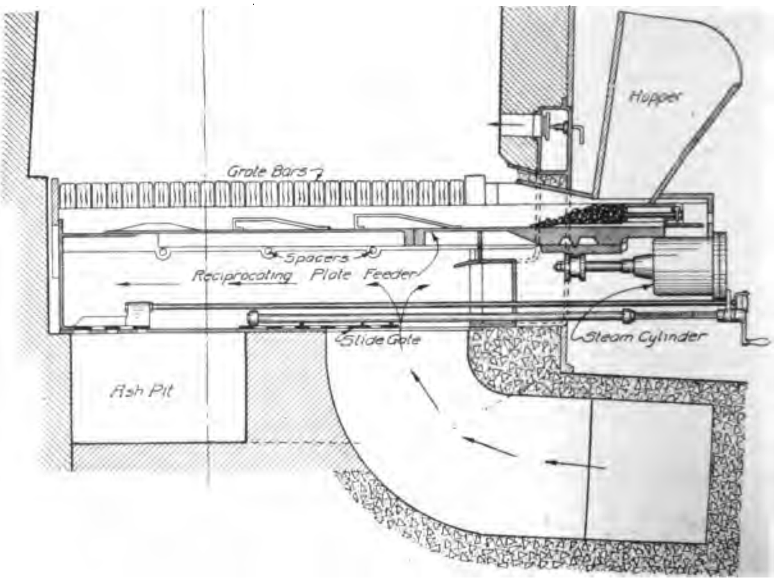


Fig. 20. Longitudinal Section of American Stoker
Courtesy of Combustion Engineering Corporation, New York City

Inclined Underfeed Type. The principle of underfeeding has for many years been recognized as excellent, but the difficulties encountered when removing the ash and refuse have made its application less attractive than would otherwise obtain. To overcome

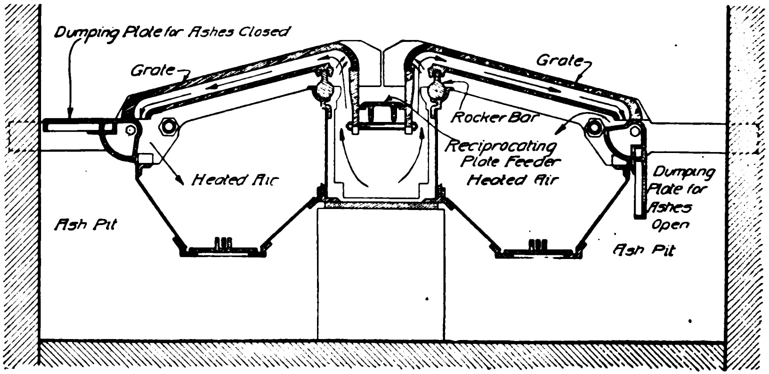

Dumping Plate for Ashes Closed
Grate
Grate
Rocker Bar
Reciprocating Plate Feeder
Heated Air
Heated Air
Ash Pit
Dumping Plate for Ashes Open
Ash Pit

Fig. 21. Cross Section of American Stoker
Courtesy of Combustion Engineering Corporation, New York City

these difficulties and others of a similar nature, the gravity underfeed stoker has been evolved. There are three principal makes: the Taylor, which was the pioneer of the type; the Westinghouse; and the Riley. All of them use the underfeed scheme and forced draft,

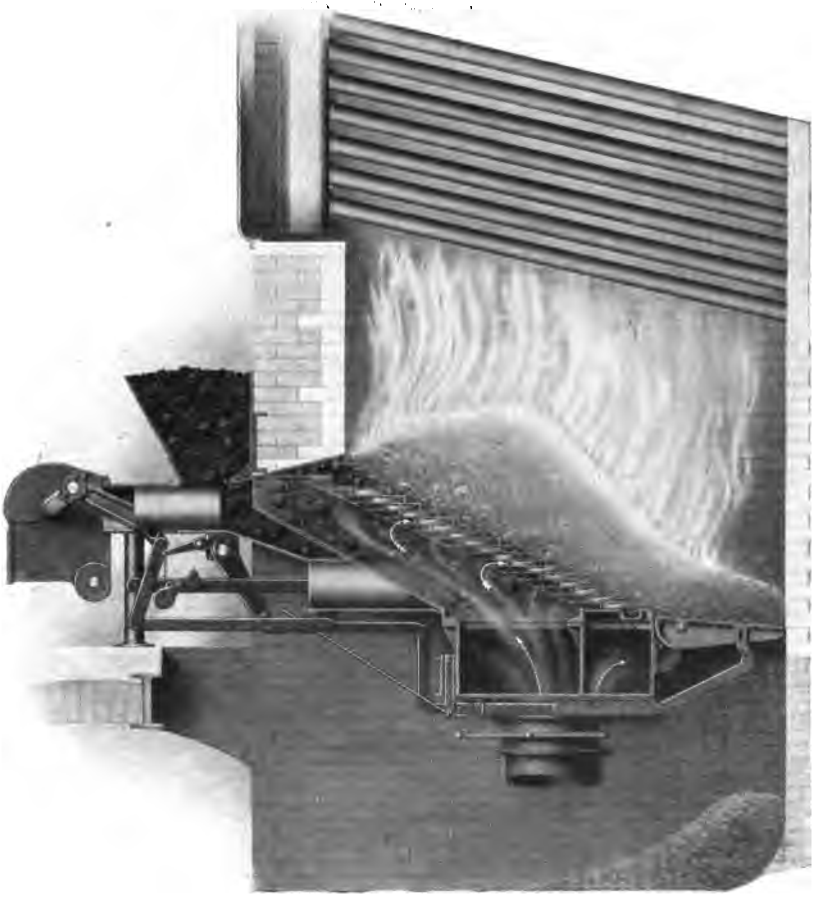


Fig. 22. Section of Taylor Stoker Through the Fire
Courtesy of American Engineering Company, Philadelphia

but their details of construction are in many particulars essentially different. This type has, in recent years, been given wide application in plants, especially where steam demands are large enough to warrant the employment of technical knowledge and skill.

Taylor Underfeed Stoker. In Fig. 22 is illustrated the Taylor type of stoker applied to a horizontal water-tube boiler, the view

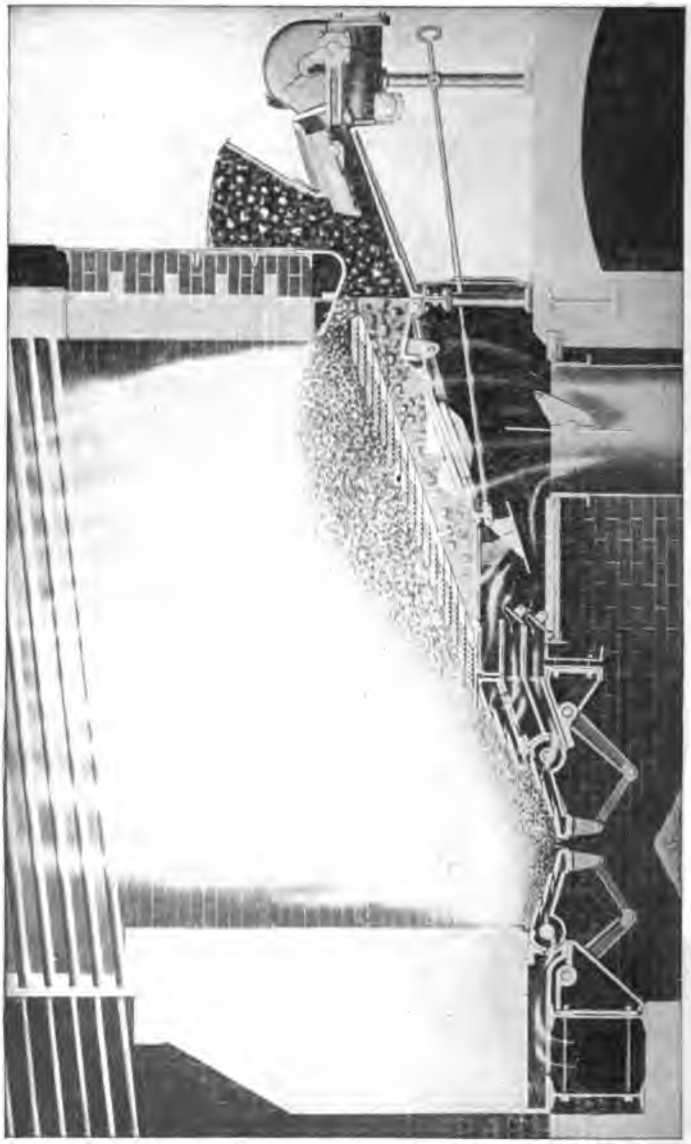


Fig. 23. Westinghouse Underfeed Stoker Applied to Horizontal Water-Tube Boiler
Courtesy of Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pennsylvania

being taken through one retort so as to show the manner of feeding coal by the upper reciprocating cylindrical plunger, its enforced movement to the lower portion of the grate by means of a second plunger, the location of the wind box, and the path taken by the air under pressure to and through the tuyères. The width of the furnace space is made up of retorts spaced about 22 inches apart, each being served with a complete plunger system. The expectation is that by the time the fuel has moved to the dumping plate, practically all of it that is combustible has been consumed, thus permitting its removal into the ash pit without appreciable fuel wastage. The illustration represents one of the earlier applications of the gravity underfeed idea not complicated by refinements to meet the requirements of all grades of bituminous fuels. Modifications take the form of plunger extensions, greater retort lengths, and better refuse dumping facilities. The ash pit construction, Fig. 22, would not be considered good practice, being wholly inadequate according to modern requirements.

Westinghouse Underfeed Stoker. Like other stokers of the underfeed type, the Westinghouse, shown applied to a horizontal water-tube boiler in Fig. 23, is made up of a series of retorts, each retort consisting of a fuel trough and two parallel tuyère boxes. Cylindrical rams push the new fuel into the furnace beneath a bed of incandescent fuel. By means of an adjustable feeding motion of secondary rams the travel of the fuel toward the rear of the furnace is continued, finally passing out over the rearmost grate section which acts as an overfeed with incandescent coke as the fuel. In this stoker the dumping section becomes active grate area by reason of air supply. The air-regulating facilities constitute one of its distinctive features, making possible the adjustment of the supply as desired at the several grate zones independent of and without impairment to the air supply of other zones.

This stoker is manufactured with a variety of dumping grates and lengths so as to permit selection to meet variations in fuel behavior as encountered in the several fuel districts of the country.

Riley Underfeed Stoker. In Figs. 24 and 25 are shown views of the Riley stoker mechanism, which, like others of its class, consists of multiple retorts placed side by side. Its distinctive feature is that the reciprocating retort sides move relative to the retort bottoms. This feature provides a means for flooding the coal over the grates and also for carrying it down toward the bottom rear of the furnace chamber. At the ends of the retorts, overfeed grate bars extend across the width of the furnace, while beyond these are rocker dump plates which are continuously agitated, thus breaking up caked refuse. Unlike other underfeed stokers only one plunger per retort is required, which feature offers the advantage of a free space beneath the grate. The air chamber is formed by the boiler side walls, floor, and front, thus inclosing the space beneath the entire grate area with the exception of the rocker dump plates. The fuel and air supply are so controlled

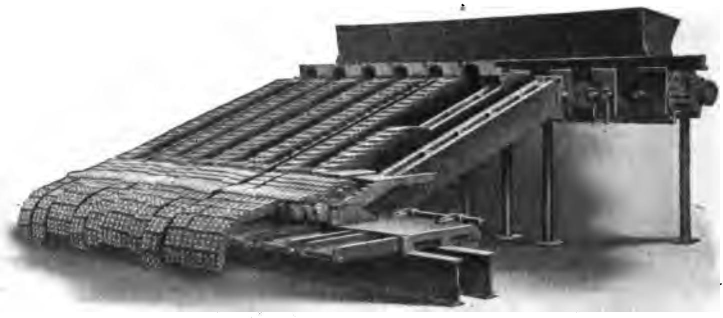


Fig. 24. Perspective View of Riley Nine-Retort Underfeed Stoker Partially Assembled
Courtesy of Sanford Riley Stoker Company, Ltd., Worcester, Massachusetts

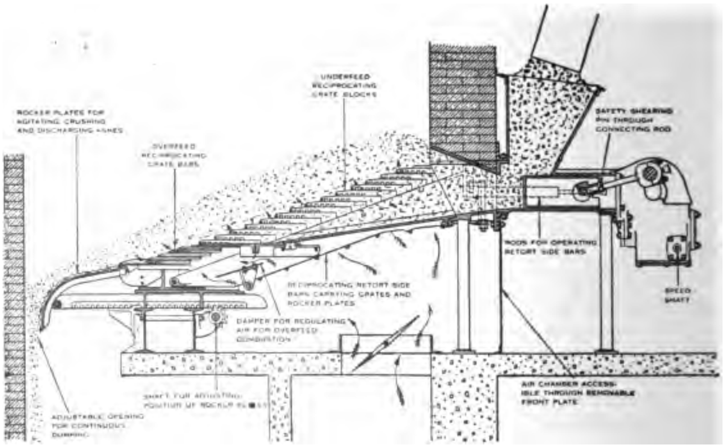

UNDERFEED RECIPROCATING GRATE BLOCKS
ROCKER PLATES FOR AGITATING CRUSHING AND DISCHARGING ASHES
OVERFEED RECIPROCATING GRATE BARS
SAFETY SHEARING PIN THROUGH CONNECTING ROD
RODS FOR OPERATING RETORT SIDE BARS
RECIPROCATING RETORT SIDE BARS CARRYING GRATES AND ROCKER PLATES
SPEED SHAFT
DAMPER FOR REGULATING AIR FOR OVERFEED COMBUSTION
AIR CHAMBER ACCESSIBLE THROUGH REMOVABLE FRONT PLATE
SHAFT FOR ADJUSTING POSITION OF ROCKER PLATES
ADJUSTABLE OPENING FOR CONTINUOUS DUMPING

Fig. 25. Sectional View of Riley Stoker Applied to Boiler Setting
Courtesy of Sanford Riley Stoker Company, Ltd., Worcester, Massachusetts

that a change in the rate of feeding the former is accompanied by a corresponding change in the latter. This stoker is capable of change in construction details to meet the requirements of variations appearing in different grades of bituminous coals.

MANIPULATION OF SPECIAL FURNACES AND MECHANICAL STOKERS

Assumptions. In the material which follows it is presumed that the important conditions requisite for the use of mechanical contrivances for feeding fuel and removing refuse have been properly provided, namely, good draft, correct furnace construction, and accessibility for suitable inspection and operation. In some instances it is also presumed that certain indicating instruments are provided, such as draft gages, without which the particular contrivances in question cannot be effectively manipulated. It is likewise expected that the operators have sufficient knowledge of boiler room practice to be able to understand the elementary methods employed in connection with the contrivances given into their charge and that the plant design is such as to represent good judgment, taking into account the character of labor available, the size of the units, and the total rated capacity of the plant as a whole. It is impossible in an article of this scope to consider all the details to be observed in every contingency, but the aim is to supply the fundamentals which must be observed to gain success.

General Features of Fuel Burning. The reader can gain the best and quickest grasp of the subject by learning a few but all-important facts respecting combustion, which are universally applicable whether dealing with hand firing or mechanical firing according to the several systems previously described. Stated briefly these facts are as follows:

(1) Only such air as enters into the combustion process is useful; any other air, wherever admitted, acts as a diluent, tends to lower temperatures and thus decreases the range of temperature through which the heat absorber (boiler) may act, and provides a larger vehicle for carrying away as waste the heat rejected into the chimney.

(2) It follows from item (1) that the less the amount of air employed in the combustion process without impairing the com-

pleteness of the process, the higher the resulting initial temperature and the larger the probable percentage of heat absorbed.

(3) The rate at which fuel will burn is dependent solely upon the amount of air which passes through the fuel bed, other conditions remaining the same. Difference in the draft above and below the fuel bed, combined with fuel-bed resistance, fixes the rate at which the fuel will liberate gases, furnace temperature remaining the same.

(4) A uniform rate of fuel feeding and corresponding uniformity of refuse removal afford the best opportunity for completeness of combustion with a minimum air supply for a given furnace space and shape.

(5) It is not possible to burn fuel with an air supply closely approximating the amount theoretically required for complete combustion without encountering incomplete combustion because the chemical avidity of carbon (the main combustible constituent of coal) for oxygen (the combustion agent in air) is not sufficiently great to cause these elements to seek each other out when widely separated. Furnace constructions imposing mixing action tend to reduce the quantity of needed excess air and are serviceable unless available draft above the fuel bed is impaired by their use.

(6) Moisture is not a combustible material. It may be useful, in some instances, in retarding the rate of combustion, thus compelling a more uniform distillation of volatile gases, or in holding coal particles in mechanical union, thus preventing sifting through grates, as is sometimes important with traveling chain grates. The use of extra or added moisture is usually attended with loss.

(7) Clinkers are the result of fusion of ash or refuse. Any cause that places refuse into zones of a higher temperature than that of fusion will cause clinkers. Disturbances to natural fuel beds by the use of slice bars, etc., puddling refuse with burning fuel will cause clinkers where they might otherwise be avoided. Where it is not possible to obtain a satisfactory rate of burning without resorting to much slicing, the furnace most probably is operating under deficient draft.

(8) High furnace temperatures without correspondingly high rates of combustion are due to "bottled-up" furnace conditions caused by too slow gas movement from the furnace because either there is too little draft to carry the gases out of the furnace or the fuel bed resistance is too great to allow the air to pass through the fuel bed in sufficient quantities.

It will thus be seen that air—its manner and rate of supply—is the one item of importance in addition to the fuel itself that determines the capacity and the economy of performance in combustion processes. Let the student apply to his problem the thought that the expensive article employed is air and that the fuel is merely incidental to the use of it and he will gain a valuable point of view.

Gravity Furnaces

General Instructions. When operating at capacities near or above full load the center and side ash-pit doors should be wide open, permitting the free access of air to both the side grates and the center grates. Under light load conditions, which might permit the center grates to be bare of fire or large holes to be present in the center grates, the most economical way to run is to close the center ash-pit doors to keep the cold air from going through the center grates. If the furnace under these conditions still causes too much steam to be made, regulate the air supply entering by means of the side ash-pit doors by partially closing them. When the load is so light that the entire grate is not required, success is sometimes obtained by closing off one whole side, doing all the firing through the coal pockets on the other side.

When burning a high volatile coal the center ash-pit doors should be left open a minute or two when poking the coal down the pockets, in order to admit an extra supply of air through the center grates.

Siftings which fall through the side grates should be placed with other new coal; this is good fuel and need not be wasted.

Mechanical Fuel Spreaders. If it is known how to fire the available fuel on a hand-fired grate, then nothing further need be said here, as mechanical fuel spreaders at their best can only duplicate hand firing. The difficulties that arise with this class of equipment are due to the fact that those in charge assume that because the coal is fed mechanically, it is necessarily fed correctly, and mistakes in firing which would not be permitted in hand firing are allowed to go unchecked when made by the machine. Nothing could be farther from good judgment. If the character of fuel when fired by hand demands a fuel thickness, say, of 7 inches uniformly distributed over the grate, the mechanical fuel spreader should be adjusted to perform the same service. In a like manner all other features need to be looked after.

Traveling Grates

General Instructions. The first principle of firing coal on traveling grates is that the fuel bed must not be disturbed by hand manipulation. If the fire is not burning properly, recourse should be taken to the adjustable features of the installation which are: dampers, grate speed, and feed-grate height. The sole guide in judging of fire conditions by eye inspection is whether the entire grate surface from the feed gate back to the bridge wall is covered with active fuel. If the fuel fails to ignite quickly at the feed gate, the ignition may be improved by draft regulation or by altering the gate height. If the fire does not extend to the bridge, a needless excess of air is admitted to the furnace unless special dampering devices make a corresponding reduction of grate possible. If the fuel passes over the inner end of the grate unburned the ash pit losses become excessive.

Thickness of Feed. Fire thickness at the feed gate may vary from 3 to 7½ inches, but for a given mechanical condition of coal and chemical composition a definite thickness within this range will be found by experiment to be satisfactory, after which determination the variables are reduced to damper and grate speed manipulation. Manifestly, the available draft in the furnace chamber influences the thickness of fire that may be employed, the greater the draft intensity the thicker the fuel bed. The rate at which the air passes through determines the rate at which the fuel will burn; consequently, a thick fire, with a given draft, tends to *reduce* the rate of combustion.

The coarser the coal the thicker should be the fuel bed and the slower the speed of grate for a given capacity. As to grate speeds, the only guide is to run the grate just fast enough to keep the active coal right up to the bridge wall but not fast enough to allow unburned coal to be carried into the ash pit. The load conditions have no direct bearing on the speed of the stoker.

Load Variations. If a load variation occurs it is met by a change of damper position. Thus a larger steam demand requires greater furnace draft. Necessarily, with greater furnace draft the coal will be burned more quickly, which calls for a greater grate speed if the grate is to be kept covered. From these facts is gathered the reason why automatic damper regulation alone will not work successfully; the coal-feeding speed must be connected with the automatic damper-moving mechanism to gain success.

Importance of Furnace Draft. The rate of burning and the degree of elasticity of the rate of burning coal on traveling grates is then a function solely of the available draft in the furnace chamber when once a furnace construction has been installed. To afford certainty of quick ignition and the use of a minimum quantity of air, the design of the furnace construction is highly important and the best guide is the experience of manufacturers of this type of stoking equipment.

From the foregoing discussion it will be gathered that it is highly important that the draft facilities should not only be ample but capable of close adjustment. The controlling damper rods or chains should be within easy reach of the fireman, and the effects of damper position should be indicated on a differential draft gage for each fire.*

Starting New Fires. To start a fire under a cold boiler, set the feed gate at about 6 inches and run in enough coal at this depth to cover about half the length of the grate. The grate can be moved in by hand, with the aid of a hand-crank provided for that purpose, if no motive power is available. After this much coal is fed in, stop the travel of the grate by throwing the stoker out of gear and then raise the feed gate to full height. Next lay a sufficient quantity of wood on top of the bed of coal clear across the entire furnace width. Before lighting the fire the stack damper should be only partially opened and the wood then lighted by lighting oily waste or the like placed just inside the feed gate. When the fire is burning briskly over the full width of the grate, the feed gate can then be let down to operating conditions and the hopper filled with coal. In time the coal underneath the wood fire will begin to ignite, and, as the burning becomes more brisk, the damper can gradually be opened. As soon as the coal begins to burn the grate can be started ahead slowly, the ignition of the coal being watched through the inspection door all the while to see that the fire does not leave the feed gate. The damper should not be opened wide until the burning coal has completely covered the grate, after which the damper can be opened quite rapidly.

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*An excellent treatise on traveling grate operation is published by the LaClede Christy Clay Products Company, St. Louis, Missouri.

Banking Fires. The load usually drops off gradually just before banking takes place, and during this time the stack damper should gradually be closed and the stoker swinging damper closed. The feed gate can then be run up to a height of about 9 or 10 inches. Retard the stoker speed, allowing the fire to burn short gradually and, as the furnace cools down, continue closing the boiler damper. The speed of the stoker and the condition of *burning short,* together with the gradual closing of the dampers, should be such that by the time the grate is half covered with dead ash, the 10-inch fuel bed will have covered the front half of the grate surface. When this condition is reached the boiler damper should be nearly closed or at least just to the point where the gases from the fire all but come out into the boiler room. The stoker is then turned out of gear. If this changing to a banked condition has been gradual, the furnace brickwork, etc., will have cooled down sufficiently to allow this 10-inch bank of coal to hold fire ten or twelve hours. If, however, the load has dropped off so quickly as to leave an extremely hot furnace at the beginning of the banking period, the first bank laid may last only a few hours, and it will be necessary at the end of that period to crank-in briskly by hand another 4 or 5 feet of green fuel, which bank will be found to hold fire twelve or fourteen hours without being disturbed. Should operating conditions be such as to make it inconvenient to lay in the second bank of fuel, the first bank can be laid with the drippage from the tailing pan underneath the stoker, and if this drippage is wet down before being fed to the hopper, it will be a further aid in causing the bank to hold fire for a long period. Just prior to banking, no more coal should be fed to the hopper than is just required for laying the bank. During the period of banking the hopper should be entirely empty, the coal in the furnace on the grates extending just to the feed gate. There should be a space of about 1 inch between the underside of the feed grate and the fuel bed. Such a space allows air to sweep above the fire, preventing smoke and slowing down the burning of the fuel. Allowing the hopper to burn dry before banking and keeping the 1-inch space between the feed gate and the fuel bed will prevent the fire from burning back into the hopper, thus preventing burning the feed-gate shoes and the cheek plates of the hopper frame.

Starting with Banked Fire. To start the boiler steaming from a banked fire, it is only necessary to take a light firing tool and break up the bank of coal, lower the feed grate to its normal position, and fill the coal hopper, after which the stack damper can gradually be opened. Care should be used that the stoker is not speeded up so fast as to carry the fire away from the feed gate, and the draft should gradually be increased, as too much draft might, after breaking up the bank, retard the burning rather than accelerate it.

Preserving Furnace Brickwork. If, when letting down the boiler, the damper is allowed to remain open while the fires are burning out, the cold air that comes in through the grates sweeps over the underneath surface of the ignition arch, chilling just the outside inch or two of the tile. This tile has a large capacity for heat and the body, or inside, of the tile retains its temperature for some time. The rapid cooling of the outside surface causes the tile to spall off; hence spalling can be prevented by gradually closing the boiler damper as the fire begins to cool down. If the dampers are left wide open after the fire begins to burn briskly, the lower surface of the tile will heat quickly while the center, or interior, of the tile will remain cool, and this quick heating may cause the bottom of the tile to drop off, or at least to crack.

The greatest enemy of an ignition arch is water, and every precaution should be taken when washing out the boiler to see that none of the water reaches the arch. Arch tiles that are kept on hand for repairs should by all means be kept under cover.

Chain Tension. It is important to keep the chain at the proper tension. An experienced operator can determine the proper amount of tension by watching the grate as it leaves the front driving sprockets. If the chain dips down and the ends of the links show prominently as the chain leaves the sprockets, the tension bolts should be tightened until the chain is straight at this point.

Wetting Coal. Some advantage is obtained by wetting the coal because it is easier to keep the fire in good condition when the coal is moist. This wetness should be just sufficient that the coal will tend to stay together when squeezed tightly in the hand but not to drip or be mushy. Under no circumstances should the water be sprayed at the hoppers; all extra moisture should be supplied before the coal is placed in the storage bins. If the spraying is done in the stoker hoppers, the water trickles through to the links and is evaporated by the furnace heat and the solid residue forms scale deposits on the chain rods, rollers, and links.

Coal Siftings. When the amount of coal which sifts down through the grates becomes excessive, it produces a very annoying condition. It should in no instance exceed 5 per cent of the coal fed to the stoker, and 3 per cent is a more common performance. The drippage pits should be cleaned regularly—say once or twice on each watch—and it is important that they be cleaned clear to the back end. Should the drippage become excessive it can be remedied by thickening up the fire, or wetting the coal, and by making sure that the proper chain tension is obtained.

Burning Refuse. Sweepings about a building containing metal clippings, nails, or other small hard metallic parts should not be burned on the chain grate stoker, as these iron parts work into the moving parts of the chain and cause trouble.

Inclined Grates

Front-Feed Type. The success of the front-feed inclined grate type of stoker depends altogether upon maintaining an active bed of fuel spread over the entire grate surface or, at least, a part of it large enough to allow sufficient coal to be burned to make the required steam within the draft facilities afforded.

The motion of the grate bars is expected to be such that there will be a progressive movement of burning fuel down the grate incline, so that when the lower dump grate is reached practically all the combustible matter has been burned out. Any act on the part of the fireman which disturbs such a progressive movement of fuel defeats the purpose of the stoker. He may interfere on occasions when the stoker fails to carry the fuel down the grate as a result of a lack of sufficient movement of the bars caused by the clinkering of the refuse. If the fuel sticks so badly that it has to be dislodged, it is a mistake to dislodge it to such a degree that large areas of fuel avalanche to the bottom. Whenever avalanching occurs and the coal has the slightest tendency to clinker, the refuse will fuse and a great deal of trouble will be experienced in getting the clinkers out. Demands for more steam are usually met by assisting the fuel in traveling down the grate and gradually introducing new fuel at the upper end. When the steam demand becomes less, recourse is taken to partially closing the boiler damper and closing the furnace doors so as to admit a less amount of air through the fuel bed.

Side-Feed Type. There is no essential difference between operating the side-feed type and the front-feed type just dealt with. There is a difference, however, in the facilities for inspecting the condition of the fire and the degree of freedom in getting at the fuel bed. The gases when leaving the fuel surface travel across the face of the fuel bed, with the result that the furnaces tend to burn out at the upper rear grate portions and require particular attention there and at the corresponding front portions, where the progressive movement of coal down the grates may be disturbed because of clinkers lodged on the front furnace wall. The mistakes in operating this type of stoker are, viz, failure to keep the hoppers filled with coal; puddling the fire with pokers and slice bars; and failure to employ the stack damper properly.

Starting Fires. To start a fire, fill the magazines and, after covering the clinker bar with wood to prevent the fuel running through into the ash pit, feed just enough coal by hand from each magazine to cover the grates. Place a small amount of kindling on top of this coal and ignite. After the fire is well started, feed coal, as required, onto the grates from the magazines by hand until the steam pressure is high enough to operate the furnace driving engine. Before starting this engine, open the cylinder drain cocks until the condensation in the steam pipe leading to the same is discharged. Also open the valve connecting the exhaust with the grate bearer of the furnace.

It will not be necessary to revolve the clinker bar for some little time after the furnace is started, but the stoker arms and the grate rocker arms should be connected to and operated by the driving bar of the furnace at a speed sufficient to keep the grates covered with coal. When refuse accumulates sufficiently at the lower ends of the grates, connect the clinker bar to the operating mechanism by dropping the driving pawl into the clinker bar ratchet gear. To prevent breakage, the stoker shafts and clinker bar should be moved by hand before they are connected to the driving bar of the stoker.

When starting after the fire has been banked, spread the coke from the banked fire along the lower ends of the grates, feed sufficient coal from the magazines to cover the grates, open the drafts, and start the driving engine.

Stopping Furnaces. To stop the furnace, see that all the coal in the magazines is fed out. If the fire is to be banked, pull the coke to the bottom of the grates and cover well with coal. The fine coal from the sifting pits is very suitable for this purpose. The ash and sifting pit doors should be closed tight and the damper opened only sufficiently to allow the gas from the fresh coal to escape. The fire door should be left open for a short time if the furnace arch is very hot when the fire is banked. The clinker bar ratchet pawl should always be raised and the grate rocker arms disconnected when the furnace is shut down.

Load Variations. When there is a sudden reduction in the demand for steam, close all doors admitting air under the grates. Leave the boiler damper open and, if the steam pressure still rises, open the fire door.

Magazine Condition. To insure an even feed of coal from front to rear, the magazines should be kept full of coal. When filling the magazines with a shovel, throw the coal well to the rear end. When feeding through the magazine top occasionally shut the slides and push the coal to the rear with a hoe, as the feed is faster at this point. Never let the magazines run so empty that light from the fire can be seen in them. Feed the coal into the furnace continuously. If it is necessary to shut down the furnace engine for a considerable time, do not let the stoker boxes stand still with coal in the magazines but give the stoker shaft one motion with the wrench every fifteen minutes. This will prevent the coal in the magazines taking fire. If coal in the magazines should take fire, do not recharge until the ignited coal is all fed out.

Fuel Bed Thickness. A V-shaped fire a little thicker over the clinker bar than on the grates will give the best results. The thickness of the fuel bed should be from 3 to 8 inches, according to the character of the coal, the draft, and the rate of duty. For fine coal or a low draft the fire should be thinner than for coarser coal or a good draft. For a fluctuating load it is good practice to work with a fairly thick fire. Should the fire on one side of the furnace get heavier than on the other, disengage the link from the stoker arm for a few minutes. If the fire is thinner than it should be, a stroke or two of the stoker shaft by hand will correct the feed.

When the furnace is in operation always keep the driving engine running with the grates in motion. If necessary to stop the feed, disengage the stoker arm links. To stop the clinker bar, raise the pawl.

Clinker Bar Speed. The speed of the clinker bar should be regulated to the ash in the coal. It is better to have it revolve at a slightly slower speed than will discharge all the ash, using the wrench occasionally to remove the refuse which accumulates, thus avoiding unnecessary waste of coke. When using coal having a large percentage of ash, take out the loose pieces alongside the clinker bar, if increasing the speed by lowering the clinker bar ratchet connection does not give the desired result. If the coal which is burned shows a tendency to clinker badly, discharge a little more steam to the fire through the grate bearer. This will prevent the clinker welding together in masses which cannot easily be removed by the clinker bar.

Draft. As a general rule, all the air to the grates should be admitted through the sifting-pit doors. With some varieties of coal, however, it is noticed that the fire at the bottom of the V gradually thickens unless a proportion of the air is admitted through the ash-pit doors. Occasionally the best results are produced by admitting most of the air in this manner. Under no circumstances, however, should the sifting-pit doors be entirely closed when the furnace is in operation.

Underfeed Stokers

Horizontal Feed. All underfeed stokers depend upon forced draft for air supply through the fuel bed and upon natural draft to carry the burning gases out of the furnace and through the boiler setting.

Starting Fires. When starting fires with steam to operate the stoker, fill the retort by means of the ram so that the tuyère blocks are covered with green coal. Scatter fire along each side and the center of the retort on top of the green coal and then start the blower, slowly increasing the speed as the fire builds up. If without steam to operate the stoker, shovel coal through the fire doors till the retort is full and the tuyère blocks are completely covered. Build a wood fire on top of the green coal, leaving the fire doors open for draft. Fire with wood until sufficient steam has been raised to operate the blower; start the blower slowly, increasing the speed as the fire builds up; then discontinue the wood and fire by hand through the fire doors in the usual manner until sufficient steam pressure is obtained to operate the ram.

Cleaning Fires. Fires must be cleaned when the accumulation of noncombustible matter in the furnace interferes with combustion. The greater portion of refuse forms in a vitrified clinker on the side grates. Lift this clinker with a slice bar and remove only the clinker with a hook. Never clean so as to expose the side grates to the intense heat of the fires. Let the ash and unconsumed coke remain on side plates; clean on dead plates and top of tuyère blocks only. The retort will keep itself clean. Shut off the forced draft when cleaning. Do not burn the fire down too thin before cleaning.

Banking Fires. To bank fires, introduce several charges of coal by means of the ram, shut off the forced draft, and close the fire doors and the damper. If the fires are banked for a long period, clinker and coke may form in the retort. The clinker should be removed and the coke broken up before attempting to operate the ram.

Inclined Underfeed. Stokers of the inclined underfeed type are dependent for their economical operation more on the indications of draft instruments and gas determinations than on judgment of fire conditions by eye inspection. It is true that when a particularly bad condition of fire exists it is possible to see that the results are bound to be economically bad, but there are conditions of bad operation, especially in the direction of supplying useless air, that are not visible and can be determined by gas analyses only. The proper manipulation of this class of stoking equipment can therefore be best accomplished under the direction of competent technical skill. The best method to pursue is to co-operate with the engineers of the companies manufacturing the equipment in determining the best way to operate, later using as a guide the draft indications observed during good trial running, occasionally checking the result by gas analyses.

The best usual operating conditions are those which prevail when almost balanced draft in the furnace is employed. If an automatic draft control to bring this about is available, so much the better, but in any case the balanced condition should be striven for.

OPERATING COMBINATIONS OF UNITS

Plant Economy vs. Boiler Economy. The discussions preceding this have been devoted to the considerations entering into the economical burning of fuel, with particular reference to the character of the equipment connected with the boiler treated as a single unit but not especially with reference to the fact that several such units are usually operated as a plant. In a measure, the matters of plant load and of its variation, which are both frequently large, were intentionally neglected so as to give more emphasis to the immediate problem of presenting the main features of boiler and furnace unit operation uninfluenced by complications set up when a battery of boilers is operated. It is wrong to conclude, offhand, that if every unit makes good use of the fuel supplied to it, the plant as a whole must necessarily be economically run, for fuel is not the only item entering into the cost of boiler operation. Mention only need be made of plant investment, labor, and maintenance costs of furnaces and boilers to justify the foregoing statement, and all of these enter into the question. More striking than any of these considerations is the fact that, whatever conclusion may be drawn from a carefully conducted series of tests over a considerable range of boiler capacity, actual running conditions show that unless the operators are compelled to busy themselves continuously either manually or mentally, in order to maintain steam pressure, attention becomes lax and as a result fuel-burning economy suffers.

Few Units with High Boiler Rating. Where there is a choice as to number of units for operating service, the tendency on the part of the directing authority should be to reduce that number to a workable minimum rather than permit a lazy performance on the part either of the equipment or the men. It does not follow‘ however, that the highest available unit operation is necessarily the best practice; to explain how to determine the reasonable stopping place in applying the higher capacity policy is the purpose of the succeeding paragraphs.

Analysis of Method. Let us assume that good daily operating performances of the boiler units of two plants are as shown in Fig. 26, in which A–A represents the efficiency of one and A'–A' that of the other over the range of capacity indicated. These lines are intended to show the average results of the units, not the possible test performances represented by A_1–A_1, which might be several per cent higher throughout the capacity range. Consider first plant A; it will be noted that it does not make a great deal of difference at what point between 80 per cent and 140 per cent of boiler rating the boiler units are operated, provided the operators obtain the realizable results as shown by the curve A–A. As a matter of fact the probabilities are that they will get, instead of A–A of Fig. 26, the curve A''–A'' of Fig. 27, which indicates departures from A–A. (Curve A–A, Fig. 27, is simply a duplication of curve A–A, Fig. 26.) The reason why the curves converge at the higher capacities is because carelessness in firing is not attended by loss of pressure when there are enough units in service to carry the plant load anyway.

Out of considerations like these comes the conclusion that it is best all around to tend to higher running rates, but to do so intelligently and with a full realization that the effects in particulars besides heat evolution and absorbtion efficiency must be weighed also.

Referring again to Fig. 26, note that the curve A'–A' for plant A' has a different position on the chart than A–A. This may be due to a variety of causes, among which may be mentioned difference in size and character of boiler units, character of furnaces, drafts, fuels, etc. Let us consider the plants to be of equal steam demand. Manifestly it would be wise to operate the units of *A′–A′* at a higher percentage of boiler rating than those of *A–A*. So it is important to know what sort of a performance with reference to capacity may be expected from the equipment dealt with. This knowledge can be gained only by obtaining evaporation and fuel figures by reliable means, preferably through the compilation of test data taken during daily operation over extended periods.

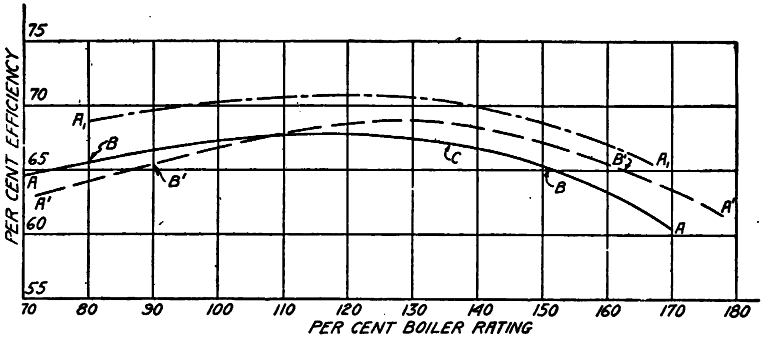


Fig. 26. Theoretical Boiler Curves Showing Variation of Efficiency with Boiler Rating

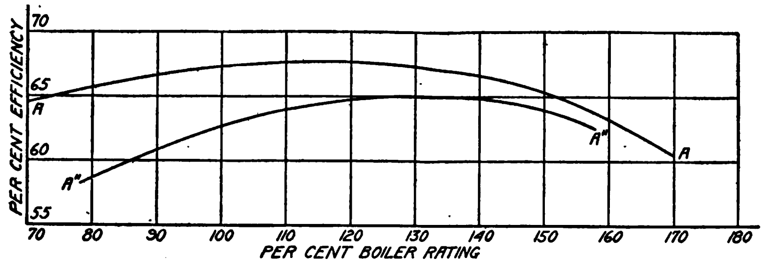


Fig. 27. Actual Boiler Efficiency Curve Compared with Theoretical Curve

Assuming that information such as given by the curve *A–A* is available and that it is known by equally reliable means what the probable steam demand will be, the method most likely to gain economical results is as follows:

(1) Estimate the likely *maximum* boiler horsepower demand for one hour, using accumulated data and experience, etc.

(2) Divide this figure by the boiler horsepower created when running a little less capacity than the *maximum capacity economical rate* as shown by compiled or plotted data. The dividend for

plant A–A, Fig. 26, would be 135 per cent of the boiler rating as shown by point C, which is a little less than B on the right, the latter being still within the range of economical performance. The quotient increased to the next larger whole number represents the total number of units to be in service.

(3) According to the load operate as many of these units as possible at the C-rating so long as none of the rest is compelled to operate below its lower capacity efficient basis as shown by point B on the left, Fig. 26.

Advantages of Plan. The effect of this procedure is as follows:

(1) When the maximum demand occurs all the operating units are running at a little below maximum capacity economical rate.

(2) As the load becomes lighter *one unit only* is brought down to its *minimum capacity economical rate,* the rest remaining on the line working at their upper limits.

(3) A still further reduction causes a second unit to be load lightened in the same manner as the first; and so on, one boiler at a time, until the minimum load is met. As the load increases the lower operated units are brought into maximum service in turn.

If the result of the adoption of this plan is to create idle units as compared with some other plan of operation, there may be absolute assurance that a substantial step has been taken in the direction of greater economy. This system is distinctly different from that of operating all boilers in service at approximately the same variation of duty in order to meet variations of load, but the results are very much better.

BOILER ROOM MEASURING INSTRUMENTS

Function of Instruments. It is so obvious that measuring instruments are essential to good boiler room performance that one is tempted to agree that the use of instruments of all kinds is justified in every instance, provided they are reliable and accurate. However, the matter is not so simple as this, for in the generation of steam as in all other mechanic arts, the character of the operating processes involved is limited by the human capabilities of the operators. It is therefore well to investigate the subject from this standpoint and state its main principles at least.

The function of instruments is to supply information—(1) to permit operators to judge of the performance while the operation is actually going on, thus permitting an intelligent adjustment if adjustment is desirable; (2) to provide responsible managers, foremen, or chiefs, with permanent records of past performances, thus supplying evidence on which to base operating reforms; and (3) to provide the basis for cost accounting, or charges for service to departments, according to service rendered.

Limits of Usefulness. Manifestly, in order for instruments to be useful under the first head, the operators must be capable of interpreting the instrument indications and be able to apply the remedies when unsatisfactory conditions exist. Under the second head the responsibility rests with the managers as well as the operators and, in addition, the records must be regularly and thoroughly digested if they are to be of any real service. Unless a genuine cost distribution system exists it is needless to provide the devices that make possible such a distribution. Experience teaches that, however desirable it may appear to be to have available the several kinds of instruments that the market affords, it is actually worth while to supply only the minimum number. However, it is highly important to have and use this minimum and the highest grade of each particular type is always justified, as is the most painstaking care in preservation and use. In other words, it is easy to overequip a plant with measuring instruments, creating a condition similar to that sometimes proposed in other branches of business where the system is so complicated that it requires another system to run it.

Types of Instruments. The measuring instruments and devices employed in boiler rooms are, viz, draft gages—indicating and recording; thermometers—indicating and recording; gas analyzing apparatus—indicating and recording; smoke gages—indicating and recording; coal weighers; water measuring or weighing devices—indicating, recording, and integrating; and steam meters—indicating, recording, and integrating.

Draft Gages. Draft obtained by the use of chimneys is the difference in pressure created by a heavier column of gas overcoming an equal volume of gas of a lighter weight per unit of volume. It should be distinguished from the air and gas itself which are mass quantities, and it should always be recognized as an intensity factor. We, therefore, speak of draft in terms of the pressure exerted by a column of water, as, for instance, .5 of an inch of water, by which is meant that the draft intensity is such as to sustain, when exerted upon a water surface, a column .5 of an inch high against gravity.

An instrument for measuring draft intensity is called a *draft gage*. There are various forms of such instruments, all of which are based upon the same principle. Where the intensities of draft are large, sufficient accuracy may be obtained by the use of a simple glass U-tube containing water, one tube end of which is in communication with the chamber or conduit of which the draft intensity is to be determined. If a suitable scale is attached, the instrument can easily be read by noting the difference in height of water level in the two legs of the tube.

A much more sensitive and, if intelligently used, more accurate instrument is that shown in Fig. 28. The glass contains a colored oil of known specific gravity. As the inclination of the tube portion determines the sensitiveness of the instrument, to obtain accuracy, the bubble vial for leveling and its position with respect to the glass portion of the gage within its working range should be carefully adjusted by the manufacturer. There is no greater difficulty in using a differential draft gage than any other less sensitive kind.

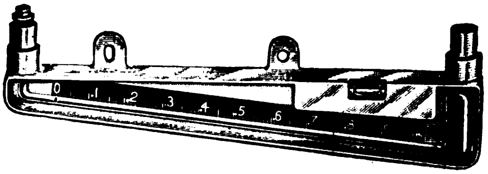


Fig. 28. Differential Draft Gage
Courtesy of Lewis M. Ellison, Chicago, Illinois

Of all instruments, the draft gage is the simplest and most useful in the steam generating art. It is no exaggeration to say that every change of condition of fuel, furnace, boiler setting, cleanliness of heating surface, or the manner of operation is reflected by the draft difference indication. To be sure, some of these draft indication changes are submerged in changes of a wider scope and, consequently, it is not to be expected that the draft gage alone will tell a complete story of boiler operation.

There is no plant, however small, that does not warrant the employment of one well-made differential draft gage, and in most instances there is needed at least one draft gage for each boiler unit, connected and located in a cool protected position so as to permit the ready determination, in turn, of the draft in the furnace region and in the boiler uptake.

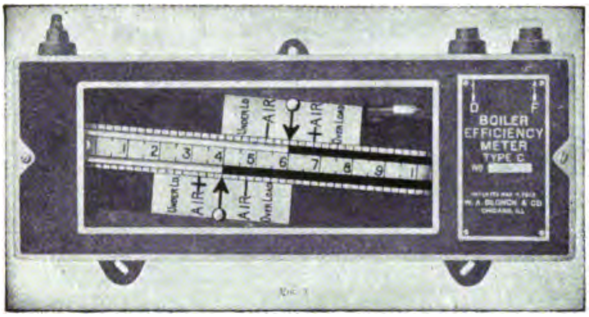
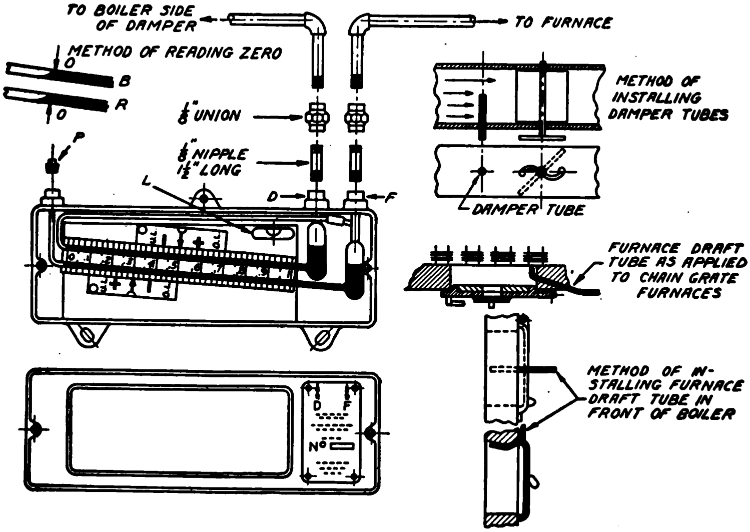


Fig. 29. View of Face of Blonck Efficiency Meter
Courtesy of W. A. Blonck & Company, Chicago, Illinois


TO BOILER SIDE OF DAMPER
TO FURNACE
METHOD OF READING ZERO
O
B
R
O
$\frac{1}{8}$" UNION
$\frac{1}{8}$" NIPPLE $1\frac{1}{2}$" LONG
P
L
D
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METHOD OF INSTALLING DAMPER TUBES
DAMPER TUBE
FURNACE DRAFT TUBE AS APPLIED TO CHAIN GRATE FURNACES
METHOD OF INSTALLING FURNACE DRAFT TUBE IN FRONT OF BOILER
D
F
No

Fig. 30. Layout Showing Method of Installing Blonck Meters

Efficiency Meter by Draft Method. An interesting and valuable adaptation of the differential draft gages for judging of furnace operating efficiency is found in the Blonck efficiency meter illustrated in Figs. 29 and 30. This meter is the pioneer of several instruments of the same type. It consists essentially of two sensitive draft gages, one connected to the furnace and the other to the boiler side of the damper. The lower gage is filled with *red oil* and shows the drop in draft through the fire, or the resistance of the fuel bed; the upper gage is filled with *blue oil* and registers the drop in draft between the furnace and the damper, or the resistance of the boiler.

Two sliding indicators are arranged so they can be set at the point of *perfect firing,* that is, the point at which the boiler is operating at its highest efficiency. These indicators are plainly marked with legends showing *underload* and *air+* at one side of the arrow and *overload* and *air−* at the other. To locate the point of perfect firing, it is necessary to determine what conditions exist when the boiler is operating at its best efficiency. The indicators should be so set that any departure from these conditions is registered. Thereafter the problem is to interpret the indications and thus make possible the remedying of a faulty operating condition.

This instrument is manufactured for all kinds of boiler furnace service and many niceties found desirable when encountering different forms of draft creating apparatus, etc., have been introduced.

Thermometers and Pyrometers. For ascertaining temperatures in ordinary boiler room work a mercury thermometer will be found intelligible to the operators and the indications will be readily understood. For the higher temperatures, such as prevail in boiler settings nearer the furnace than the uptake, a thermocouple connected to an indicating millivoltmeter is usually very desirable. When used well within safe operating ranges the *relative* indications are usually found to be fairly accurate; the absolute indications are sometimes inaccurate, especially if the couple has been subjected to excessive temperature. Temperature recording instruments, principally of the clock-dial type, are also manufactured.

Flue Gas Analyzing Apparatus.* *Description of Orsat Type.* The Orsat apparatus, illustrated in Fig. 31, is generally used for analyzing flue gases. The burette *A* is graduated in cubic centimeters up to 100 and is surrounded by a water jacket to prevent any change in temperature from affecting the density of the gas being analyzed.

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*Courtesy of The Babcock & Wilcox Company, New York City.

For accurate work it is advisable to use four pipettes *B*, *C*, *D*, and *E*, the first containing a solution of caustic potash for the absorption of carbon dioxide, the second an alkaline solution of pyrogallol for the absorption of oxygen, and the remaining two an acid solution of cuprous chloride for absorbing the carbon monoxide. Each pipette contains a number of glass tubes, to which some of the solution clings, thus facilitating the absorption of the gas. In the pipettes *D* and *E* copper wire is placed in these tubes to re-energize the solution as it becomes weakened. The rear half of each pipette is fitted with a rubber bag, one of which is shown at *K*, to protect the solution from the action of the air. The solution in each pipette should be drawn up to the mark on the capillary tube.

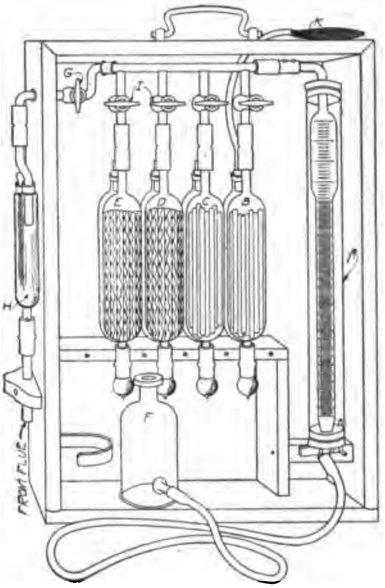

Fig. 31. Diagram of Orsat Apparatus for Analyzing Flue Gas
Courtesy of The Babcock & Wilcox Company, New York City

Method of Use. The gas is drawn into the burette through the U-tube *H*, which is filled with spun glass, or similar material, to clean the gas. To discharge any air or gas in the apparatus, the cock *G* is opened to the air and the bottle *F* is raised until the water in the burette reaches the 100 cubic centimeter mark. The cock *G* is then turned so as to close the air opening and allow gas to be drawn through *H*, the bottle *F* being lowered for this purpose. The gas is drawn into the burette to a point below the zero mark, the cock *G* is then opened to the air, and the excess gas is expelled until the levels of the water in *F* and in *A* are at the zero mark. This operation is necessary in order to obtain the zero reading at atmospheric pressure.

The apparatus and all connections leading thereto should be carefully tested for leakage. Simple tests can be made; for example, if, after the cock *G* is closed, when the bottle *F* is placed on top of the frame for a short time and again brought to the zero mark, the level of the water in *A* is above the zero mark, a leak is indicated.

Before taking a final sample for analysis, the burette *A* should be filled with gas and emptied once or twice, to make sure that all the apparatus is filled with the new gas. The cock *G* is then closed and the cock *I* in the pipette *B* is opened and the gas driven over into *B* by raising the bottle *F*. The gas is drawn back into *A* by lowering *F*, and when the solution in *B* has reached the mark in the capillary tube, the cock *I* is closed and a reading is taken on the burette, the water in the bottle *F* being brought to the same level as the water in *A*. The operation is repeated until a constant reading is obtained, the number of cubic centimeters being the percentage of CO_2 in the flue gases. The gas is then driven over into the pipette *C* and a similar operation is carried out. The difference between the resulting reading and the first reading gives the percentage of oxygen in the flue gases.

The gas is next driven into the pipette *D*, then given a final wash in *E*, and then passed into the pipette *C* to neutralize any hydrochloric acid fumes which may have been given off by the cuprous chloride solution, which, especially if it be old, may give off such fumes, thus increasing the volume of the gases and making the reading on the burette less than the true amount.

The steps in the process must be performed in the order named, as the pyrogallol solution will also absorb carbon dioxide, while the cuprous chloride solution will also absorb oxygen.

As the pressure of the gases in the flue is less than atmospheric pressure, they will not of themselves flow through the pipe connecting the flue to the apparatus. The gas may be drawn into the pipe in the way already described for filling the apparatus, but this is a tedious method. For rapid work a rubber bulb aspirator connected to the air outlet of the cock *G* will enable a new supply of gas to be drawn into the pipe, the apparatus then being filled as already described. Another form of aspirator draws the gas from the flue in a constant stream, thus insuring a fresh supply for each sample.

The analysis made by the Orsat apparatus is volumetric; if an analysis by weight is required, it can be found from the volumetric analysis by computation based on the molecular weights of the gases involved.

Other Types. There are forms of manually operated gas analyzing apparatus other than the one described above, but they are all based on the Orsat principle. Many ingenious forms have been developed with a view toward making the instrument less liable to breakage and more portable. Many attempts have been made to evolve recording or continuous CO_2 instruments by far the most of which have been failures, especially when placed in the hands of boiler room engineers. Certainly there has been no recording CO_2 instrument constructed that, considered in connection with boiler furnace practice, warrants the employment for its own sake of the necessary skill to keep it working.

Smoke Indicators and Recorders. Smoke indicators and recorders are gradually coming more into favor as their importance is appreciated. Where an indicator is wisely employed the results are gratifying. The smoke recorder has the added advantage of providing evidence of failure of operators to carry out instructions in case the record shows avoidable smoke.

Smoke Indicators. Smoke indicators are constructed on the simple principle of so placing an artificial light opposite an opening in the boiler stack connection that it shines into the breeching. When the flue gases are clear, the light will shine across the breeching into a tube connection fitted with mirrors and reflectors so as to project light rays upon a ground-glass disk, or *moon.* An obstruction to light passage by smoke will cause this moon to darken corresponding to the density of the smoke. The fireman may thus have a fair conception of the exhalation coming from the top of the stack without looking at the stack at all and can act to remove the cause of the smoke at once.

Smoke Recorders. Smoke recorders are constructed on the principle of taking minute samples of flue gas at frequent regular intervals and projecting these as rapidly as taken upon a soft paper sheet or ribbon passing by the gas ejecting nozzle. The instrument must not only take a fair sample of the gas but must show a paper record closely duplicating in appearance the density of the smoke column coming from the breeching or stack. The device manufactured by the Hamler-Eddy Smoke Recorder Company, of Chicago, is the best of its kind and is a very ingenious, accurate, and otherwise reliable instrument.

Coal Weighing Instruments. Coal weighing instruments are in every instance built upon the ordinary platform scale system of lever arms and scale beam and are usually an integral part of a coal larry system delivering coal to stoker hoppers in turn. The value of keeping accurate records of the coal consumed by each boiler is coming to be better appreciated, and unless by the use of this form of apparatus other operating features are adversely affected, coal weighing is well worth any reasonable expenditure of effort and money, especially when data concerning the water evaporated is also available.

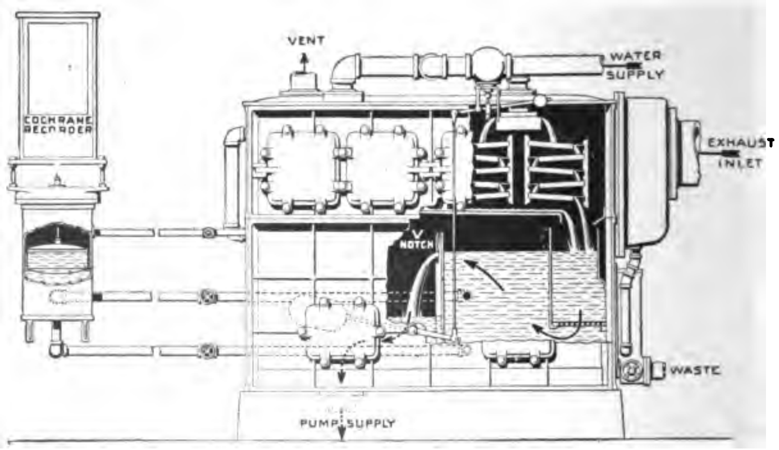

Fig. 32. Cochrane Metering Heater with Outside Chamber for Recorder Float
Courtesy of Harrison Safety Boiler Works, Philadelphia, Pennsylvania

Water Measuring or Weighing Devices. *Integrating Meter.* Water measuring or weighing devices are of several forms, of which the most common is the familiar type of integrating meter placed on water supply lines. For boiler feed, especially when the water is hot, the serviceability, or at least the accuracy, of such meters is open to question, though of course they may always be calibrated. Meters are always, or should be, installed in by-passes to permit removal for repairs.

V-Notch Meter. A second type of meter known as the V-notch is shown in Fig. 32 as a part of a feed-water heater. The principle of operation is to determine by accurate means the height of the water flowing over a V-shaped weir and to apply this water head in a computation based upon other known experimental factors. The resulting quantity of flow is made manifest by indicators, a recording chart, and an integrating meter when connected up with suitable clock and other mechanism, the whole being an accurate and convenient manner of determining feed-water quantities.

Venturi Meter. A liquid flowing through a contracted area of pipe constructed as shown in Fig. 33 will exert varying pressures at two sections *A* and *B*, the pressure at *B* being less than at *A* because the velocity at the throat is higher than that at the inlet section. By properly proportioning the pipe this pressure loss is restored at section *C*. The loss of pressure at the throat can be accurately measured by a manometer gage and is found to increase approximately as the square of the throat velocity, so that if the velocity at *B* is doubled the pressure difference becomes about four times as great. The use made of this phenomenon is simply to connect the inlet section to one and the throat section to another of two vertical wells, containing mercury baths, communicating at their bottom end means of a small pipe connection. In each well is a heavy float resting on mercury, a part of which flows from one well to the other in direct proportion to the difference in the two pressures. Consequently, one float rises as the other descends and this movement is transferred through substantial rack and spur gearing to an indicator dial hand shaft.

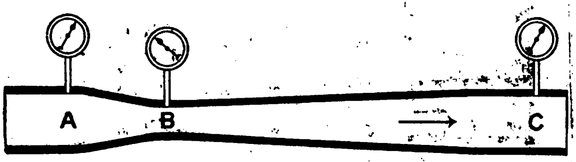

Fig. 33. Section of Venturi Meter Tube

A typical installation is illustrated in Fig. 34, which shows the connections at the Venturi pipe with two leads of small pipe transmitting the pressures at the inlet and throat sections to the mercury wells in the lower back part of the instrument case. The front displays a recording chart on top, an integrating mechanism immediately below it, and a rate-of-flow indicator.

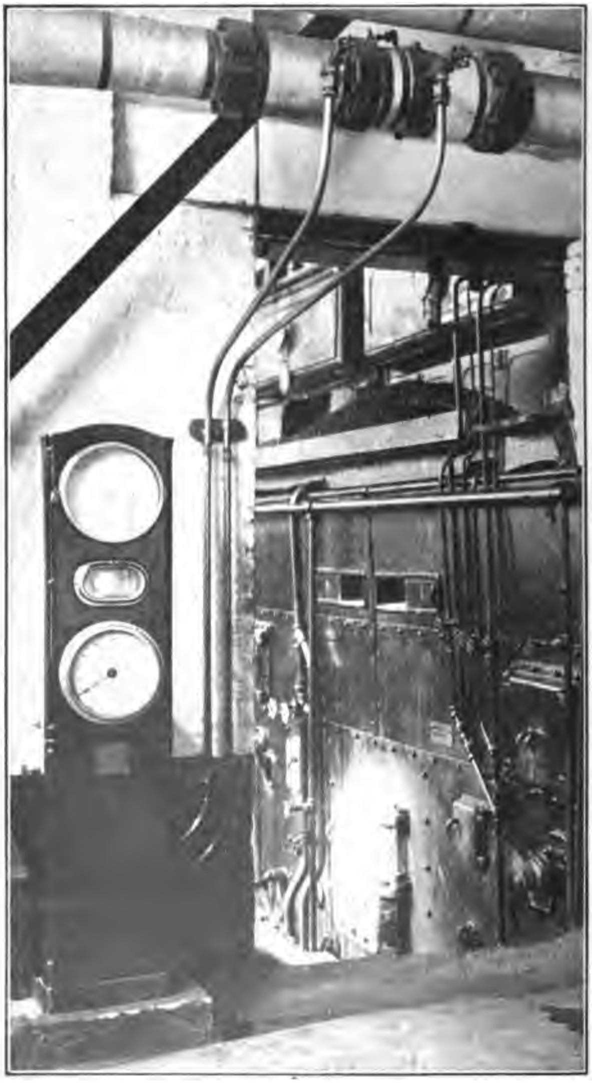

Fig. 34. Venturi Meter Installation
Courtesy of Builders Iron Foundry, Providence, Rhode Island

Steam-Flow Meters. To illustrate the principle of action of the Pitot tube as applied to steam-flow meters, an elementary form is shown in Fig. 35. Assume that two small pipes are inserted in the main pipe in such a manner that one opening, called the *leading opening,* faces against the direction of flow and the other opening, called the *trailing opening,* faces in the direction of flow of the steam, water, air, or gas being measured. These two pipes are connected to the two glass legs of a vertical U-tube containing mercury.

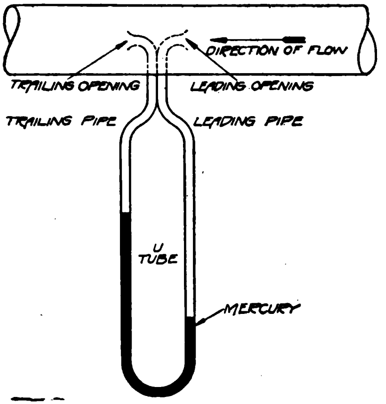

Fig. 35. Diagram Showing Principle of Action of Pitot Tube

It is evident that the steam, water, air, or gas when flowing impinges against the leading opening and sets up a pressure in the leading pipe, which equals the static pressure plus a pressure due to the velocity head. The drag of the gas or fluid over the trailing opening lowers the pressure in the trailing pipe. Owing to the differential pressure the mercury in the U-tube is deflected until the weight of mercury represented by the difference in the two columns exactly balances the differential pressure of the flowing medium. The amount of deflection is indicative of the rate of flow, other conditions remaining the same. Therefore it is feasible to expect a true indication, within reasonable ranges, of the quantities passing through the Pitot tube section of the pipe if the tube is properly combined with suitable indicating and recording mechanisms.

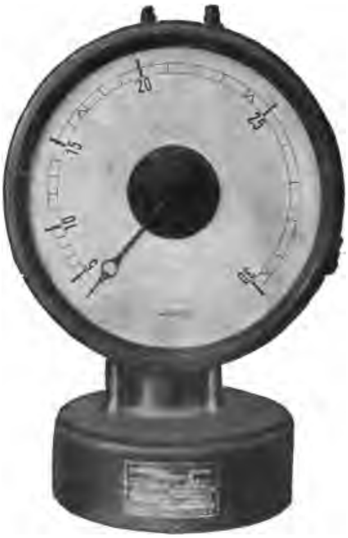

Fig. 36. Indicating Flow Meter
Courtesy of General Electric Company, Schenectady, New York

The General Electric Company manufactures for steam, gas, air, and water use a number of different types of instruments from the simplest indicating flow meter, shown in Fig. 36, to the most complicated indicating, integrating, and recording types. Translating on indices or charts the differences in pressure exerted by the two Pitot tube pipe leads gives rise to several devices, some depending upon pure mechanical mercury height measurement and others upon electrical contact and resistance variations.

CARE OF BOILERS

BOILER MANAGEMENT

Importance of Good Care. Any amount of time spent in the proper care of a steam boiler will be amply repaid, for this is of great importance. The boiler, of course, should be so designed and constructed that all parts can be readily inspected and cleaned; but this is of little benefit unless proper and rigid inspections are made. All internal fittings, such as fusible plugs, water alarms, feed pipes, and the like, should occasionally be examined to see if they are tight and in good working order. It is especially important that if traces of oil be found the causes should immediately be removed. If due care is not given to the boiler, its life will be materially shortened.

Care of Pressure Apparatus. The following operating rules have been established by the Hartford Steam Boiler Inspection and Insurance Company and should be carefully followed, whether or not the boiler is insured by the above-mentioned company:

Condition of Water. The first duty of an engineer, when he enters his boiler room in the morning, is to ascertain how many gages of water there are in his boilers. Never unbank or replenish the fires until this is done. Accidents have occurred and many boilers have been entirely ruined through neglect of this precaution.

Low Water. In case of low water, cover the fires immediately with ashes; or, if no ashes are at hand, use fresh coal and close the ash-pit doors. Never turn on the feed nor tamper with or open the safety valve. Let the steam outlets remain as they are.

In Case of Foaming. Close the throttle and keep it closed long enough to show the true level of the water. If that level is sufficiently high, feeding and blowing will usually suffice to correct the evil. In case of violent foaming, caused by dirty water or by change from salt to fresh water or *vice versa,* in addition to the above, check the draft and cover the fires with fresh coal.

Leaks. When leaks are discovered, they should be repaired as soon as possible.

Blowing Off. If the feed water contains sediment forming matter, the boilers must be blown down at regular intervals. It will usually suffice to blow down one inch of water each watch. In case the feed water contains foam producing matter, the blowing down must be sufficient to make it possible to observe a fairly steady gage glass indication. When surface blow cocks are used, they should be opened frequently for a few minutes at a time.

Filling Up the Boiler. After blowing down, allow the boiler to become cool before filling again. Cold water pumped into hot boilers is very injurious, on account of the sudden contraction.

Exterior of Boiler. Be careful that no water comes in contact with the boiler exterior, either from leaky joints or from other causes.

Removing Deposit and Sediment. In tubular boilers, the handholes should be opened frequently, all collections removed, and fore plates carefully cleaned. Also, when boilers are fed in front and blown off through the same pipe, the collection of mud or sediment in the rear end should be removed frequently.

Safety Valves. Raise safety valves cautiously and frequently to prevent their sticking fast in their seats.

Safety Valve and Pressure Gage. Should the gage ever indicate the limit of pressure allowed, see that the safety valves are blowing off. In case of difference, notify the insurance company's inspector.

Gage Cocks, Glass Gage. Keep the gage cocks clear and in constant use. Glass gages should not be relied on altogether.

Blisters. When a blister appears, immediately have it carefully examined and trimmed or patched, as the case may require.

Clean Sheets. Particular care should be taken to keep sheets and parts of boilers exposed to the fire perfectly clean; also all tubes, flues, and connections well swept. This is particularly necessary where wood or soft coal is used for fuel.

General Care of Boilers and Connections. Under all circumstances, keep the gages, cocks, etc., clean and in good order, and things generally in and about the boiler room in a neat condition.

Getting Up Steam. In preparing to get up steam after the boilers have been open or out of service, great care should be exercised in making the manhole and handhole joints. Safety valves should then be opened and blocked open, and the necessary supply of water run in or pumped into the boilers, until it shows at second gage in tubular and locomotive boilers; a high level is advisable in vertical tubulars as a protection to the top ends of the tubes. After this is done, fuel may be placed on the grate, dampers opened, and fires started. If the chimney or stack is cold and does not draw properly, burn some oily waste or light kindling at the base. Start the fires in ample time, so that it will not be necessary to urge them unduly. When steam issues from the safety valve, lower it carefully to its seat and note the pressure and behavior of the steam gage. If there are other boilers in operation, and stop valves are to be opened to place boilers in connection with others on a steam-pipe line, watch those recently fired up, until pressure is up to that of the other boilers to which they are connected; then open the stop valves slowly and carefully.

The precaution just mentioned is automatically taken care of if all the boilers on the same steam main are equipped with automatic stop-and-check valves and the additional control valve on the boiler being brought up to steam pressure is open, so that the automatic valve can operate as intended.

Care of Setting and Attachments. *Avoiding Air Infiltration.* While the care of the boiler or pressure apparatus is important, it is just as important that the enclosure of the boiler and its furnace receive careful attention. The penalty for not so doing is to sacrifice efficiency in operation. It is impossible to emphasize too strongly the necessity for maintaining brickwork tight, for every bit of air filtered into the setting without taking part in the combustion process represents a direct loss. Close investigation of this subject discloses the fact that engineers and firemen do not appreciate the harm that can result from a failure to attend to boiler settings by not preventing air leakage and radiation losses, though they usually are keen to attend to the *safety* elements of the installation in their charge. It is conservative to say that the money losses that can be avoided by reasonable care of boiler settings greatly exceed the money losses due to boiler failures.

CORROSION

There are several causes which tend to shorten and destroy the life of every boiler. These may be divided into two general classes, chemical and mechanical, and are usually the result of improper feed water or of improper care. Pure water, free from air and carbon dioxide, has no evil effect on the iron; but all natural waters, whether from rain, lake, river, or sea, contain air and a little carbon dioxide in solution, and such water will cause iron to corrode, even though no other impurities are present. Sea water, heated under a steam pressure of 30 pounds, even if it contains no air, will liberate a little hydrochloric acid, which instantly attacks the iron of the boiler unless counteracted by a chemical agent.

EXTERNAL CORROSION

Causes. There are two forms of corrosion, external and internal. External corrosion may be due to faulty setting, to improper care, to moisture from external sources, or from leakage from joints and valves. A large amount of external corrosion is the result of setting boilers in a mass of brickwork, which readily absorbs moisture, and which, when not under fire, is likely to keep the boiler plates damp. The exterior of a boiler encased in brickwork, moreover, is not so easily accessible, and a considerable amount of deterioration may take place without being readily detected.

Prevention. Internally fired boilers are supported on saddles and are easily accessible; and the magnesia or asbestos lagging with which they are usually covered will tend to absorb a certain amount of moisture, which will be given off when hot, thus helping to keep the boiler dry. If a leak of appreciable size occurs, the covering will become softened and its presence will be detected at once and repairs made. The exterior of an internally fired boiler, being at all times accessible, can be properly taken care of, which is not true of a boiler set in brickwork. Rivets and riveted joints should, as far as possible, be kept out of contact with the fire.

Water-tube boilers are for the most part so enclosed that the tubes do not come in direct contact with the brickwork. In this respect the criticism just offered to brick enclosures for boilers does not hold. Even with water-tube boilers brick comes in contact with metal, though some settings are remarkably free in this respect.

INTERNAL CORROSION

Causes. This is the result of the chemical action of impure feed water. It may occur in the form of a general corrosion or wasting away of the boiler plates, or in the form of pitting or grooving, the effects of which are likely to be local. Pitting and general corrosion are entirely the result of chemical action, while grooving is the result of chemical and mechanical action combined.

It is not easy to discover general corrosion, because it acts more or less uniformly over a large surface. Sometimes the rivet heads rust in proportion to the plates, so that the wasting away of the plates is not easily noticeable. A uniform corrosion is the hardest to detect, and can usually be discovered only by drilling the boiler and gaging the thickness of the plate. If the thickness of the plate is found to be materially reduced, the working pressure of the boiler should be lowered in proportion.

Sometimes the water will attack the plates only in the vicinity of the water line, in some instances confining the damage to a belt 6 inches or 8 inches wide. Sometimes a few rivets below water level will be corroded, the remainder being in comparatively good condition. Often the stays are weakened more rapidly than the plates, and the screw threads of a stay may be badly corroded while the shank of the stay remains uninjured.

Pitting. Fatty acids, which are likely to come over in the feed water if vegetable oils are used to lubricate engine cylinders, are especially active in producing small pits throughout the interior of the boiler. Pitting appears in the form of small holes or in patches from ¼ inch to 1 inch in diameter, or even as irregularly shaped depressions. If the holes are small and close together, the plate is said to be honeycombed. It is generally believed that this phenomenon, the result of chemical action, is due to a lack of homogeneity in the material of the boiler, although an entirely satisfactory explanation has not yet been given. Pitting may also be caused by galvanic action, which may take place especially if sea water is used. As pitting occurs when there is no cause whatever for galvanic action, this can be only a secondary cause at best. It is reasonable to suppose that acids will attack the most susceptible portions of the plate; and if there is any lack of homogeneity in the iron, it is probable that the places or spots most favorable to chemical attack will suffer first.

Grooving. Grooving is probably the result of straining, springing, or buckling of the plates, aided by local corrosion or by the same forces which cause pitting. Straining of the plates may be due to insufficient or improper staying, thus causing the plates to spring back and forth as the steam pressure varies. This phenomenon is most commonly found in stationary boilers of the Cornish or Lancashire types appearing in the flat end plates around the edge of the angle iron, or in the root of the angle iron. Too rigid staying of the ends by gussets or diagonal stays, or too great a difference in expansion between different parts, is almost sure to produce grooves.

When a sheet of a boiler is flanged to a small radius, as in some forms of boiler construction, like the head of a shell, it is commonly supposed that a "breathing" action takes place (due to variations of internal pressure and heat stresses) which sets up "fatigue" of the metal, concentrating this stress over a small distance in the curve of the flange. A crack or groove may then develop along the line of greatest stress and, if allowed to progress, may result in a disastrous explosion. The best boiler designers recognize this as a most important item to be considered, and overcome the grooving tendency by providing long radius flanges.

Internal grooving may be caused as the direct result of excessive calking, which, by injuring the surface of the metal, exposes it to the corrosive action of the feed water. It is to be expected that if strains which cause the plates to come and go are set up in the boiler —especially if the stresses can be concentrated along a definite line —a weakness will be developed there, and it will be a susceptible point for chemical attack. Sometimes grooving is so fine as to appear to be a mere crack. But the crack, although perhaps only $\frac{1}{64}$ inch in width, may extend into the plate for a considerable depth. Grooves are not readily detected and, if allowed to continue for any length of time, are likely to produce serious results.

Prevention. The best way to prevent internal corrosion is to use water that has no corrosive effect on the plates. If internal corrosion has begun, a change of feed water may prolong the life of the boiler, but in many instances it is cheaper to build a new boiler than to change the water supply frequently. Sometimes the introduction of a thicker plate at places where the water is found to be most active will be advisable; but, as these plates are stronger than the rest of the boiler, the strains will not be uniformly distributed, and stresses are likely to concentrate along the edge of this heavy plate, which will be a susceptible point for the formation of grooves.

The acidity of the feed water may be neutralized by some alkaline substance, such as soda, before it enters the boiler. The amount of soda to be used varies with the acidity of the water; but it should always be used in the smallest possible quantity, as the soda is likely to produce priming in the boiler and will be injurious if there is much salt present. Vegetable oils should not be used for cylinder lubrication if the condensation is to be fed back to the boiler, as such oils contain acids which will always produce injurious effects. Mineral oils alone should be used.

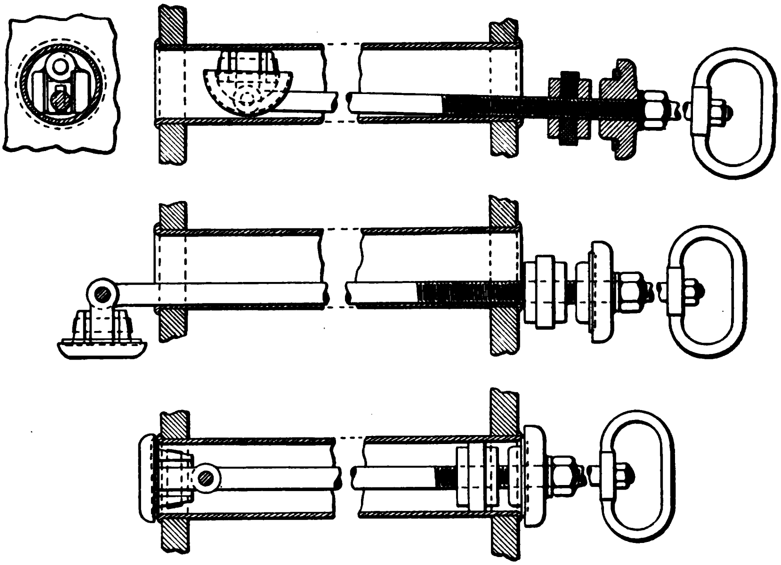

Fig. 37. Tube Stopper Designed for Insertion without Drawing Fire

To allow for a general corrosion, $\frac{1}{16}$ inch to $\frac{3}{16}$ inch extra thickness of shell should be provided. All seams of a boiler should be tight, and no welded tubes should be used, as pitting and grooving are likely to occur in the vicinity of the weld. When not in use, no moist air should be allowed in the boiler. A boiler can be thoroughly dried out either by the application of heat or by putting lime into it, which will readily absorb the moisture.

The water fed to the boiler should be thoroughly filtered to remove as much grease as possible, for, although mineral oil is not likely to cause pitting, it has a serious effect in other ways.

Tube Stoppers. It frequently happens, when fire-tube boilers are under pressure that leaks occur in the tubes through pitting, defective welding, or the development of cracks. Formerly, when this occurred, the fire was drawn and the ends of the tube plugged with hardwood bungs driven hard home or with iron plugs calked in. With high pressures, such procedure is impossible. Tube stoppers used for high pressure are joined together by a tie-rod of some sort. They are usually wedge-shaped; and the tie-rod, passing through the stopper at one end, with a plug at the other end, can be screwed tight up.

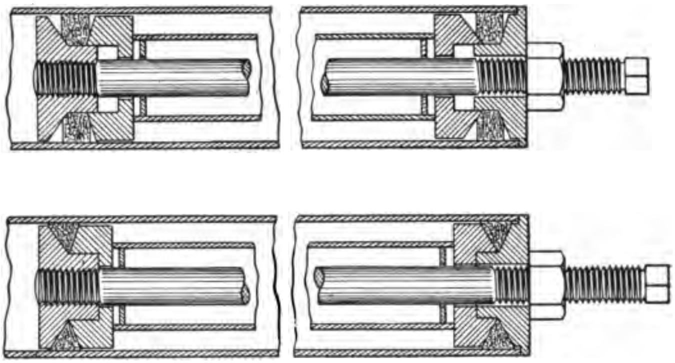

Fig. 38. Type of Tube Stopper Using Pistons with Asbestos Packing

The simplest form of stopper has to be inserted from the rear, and necessitates drawing the fire; but Fig. 37 illustrates a stopper which can be inserted without drawing the fire. At the end of the rod is hinged a folding bung, which can be passed through the tube and which opens out in the combustion chamber before being pulled into position. At the smoke-box end of the boiler, an india-rubber washer, pressed between two pieces of metal, affords temporary protection while the plug is being put in position. The stopper can then be screwed up tightly with a handle provided for that purpose.

Fig. 38 illustrates another arrangement which can be inserted in the leaky tube without drawing the fire. The ends, being in the form of stuffing glands, press an asbestos packing hard against the side of the tube.

INCRUSTATION OR SCALE FORMATION

Causes in General. The incrustation formed by the accumulation of the deposit of sediment in the feed water is called scale or sludge. The solid matter in the feed water may be precipitated by the rise in temperature, or left behind as the result of the evaporation of the water. Some of these precipitates remain soft and can be blown out, while others deposit as hard scale, especially where the heat is most intense. A thin coating of scale in itself is beneficial, for it keeps the water from direct contact with the iron, and prevents corrosion and pitting; but the danger is that if a thin scale forms, a thicker one will form, and this heavy scale, being a poor conductor of heat, not only causes considerable waste of fuel, but allows the plates next the furnace to become overheated, with the result that they are likely to give way, and the boiler may collapse or bag.

The amount of solid matter held in solution is measured in grains per gallon. The quantity varies greatly in waters from different sources, but is seldom over 40 grains per gallon. It is not the quantity of matter in solution, but its nature, that determines the influence of feed water. With proper attention to the boiler, the presence of a certain amount of carbonate or sulphate of soda would not be injurious; while the same number of grains per gallon of salts of lime would cause serious trouble. Salts of lime (calcium), together with carbonate of magnesia, are the solids most frequently found, and are the most troublesome. Hard water contains considerable quantities of lime. So-called soft water has usually but little solid matter in suspension, but it may contain vegetable or organic impurities that will cause corrosion or pitting.

Oil. The oil used in the engine is likely to get into the boiler through the feed water, if it is not carefully filtered or passed through a *grease extractor* or *oil separator*. The oil is likely to be deposited on the sides and tubes of the boiler, and not only is a poor conductor of heat, but, mingling with the sediment which is precipitated from the hot water, produces a mixture which is readily baked on to the boiler plates and is especially obstinate and difficult to remove. Because this oily deposit resists heat transmission, the metal adjacent to it may become overheated and fail to withstand the boiler pressure and give away. These failures are often very costly to both life and property. There are efficient oil separators now on the market, which will remove practically every trace of oil.

Carbonate of Lime. Carbonate of lime is held in solution in water by an excess of carbondioxid. As the water is heated, the excess of carbondioxid, or carbonic acid, is driven off, and the carbonates will be precipitated in the form of a whitish or grayish sediment of the consistency of mud. If these precipitates are not mixed with impurities, they may be washed out of the boiler after it has been allowed to cool; but if there is oil, organic matter, or sulphate of lime, the deposits are likely to become hard. They may readily be drawn off through the bottom blow-out; but if there is much pressure in the boiler, the blow-out valve should be opened only for a very short time. If a considerable amount of water is blown out while the boiler is still very hot, a large part of this precipitation is likely to be baked on to the tubes and interior of the boiler in a manner that defies removal. Short and frequent blowings will accomplish the desired result; for while the boiler is in action these precipitates are more or less in motion, and frequent blowing will keep the boiler clear. Oil and various organic matters rising to the surface can easily be removed by frequently opening the surface blow-out.

Sulphate of Lime. This troublesome salt, like the carbonate of lime, is precipitated with a rise of temperature; and at 280° F., none is left in solution. This sediment is likely to form a hard, adhering scale; but if a little carbonate of soda, or soda ash, is introduced with the feed water, calcium carbonate is precipitated in the form of a white powder which can be readily washed out. The carbonate of soda should be introduced at regular intervals, a portion of it being dissolved in water which can be mixed with the feed in the hot well. As little soda as possible should be used, as it is likely to cause priming and foaming. The hardness of the scale formed by the sulphate of lime depends on the other impurities in the water and on the temperature, and consequently the amount of soda that can safely be used can be determined only by trial. Ammonium chloride, commonly called sal-ammoniac, is sometimes used to break up these lime compounds, but is not always desirable, as it may break up the chlorides if other conditions are right, thus forming free chlorine, which attacks the boiler.

Carbonate of Magnesia. Carbonate of magnesia is seldom found in such large quantities as calcium salts. Like the carbonate of lime, it is precipitated in hot water. If there is any oil or organic matter present, it is likely to form an injurious precipitation.

Iron Salts. Iron salts form a reddish incrustation which is very injurious to boiler plates. Brackish water containing chloride of magnesium is also injurious; for, when heated, the chloride decomposes, forming magnesia and hydrochloric acid, the latter rapidly corroding iron.

A piece of thick scale broken from the plates of the boiler will show a series of layers of various thickness, some of them crystalline and some amorphous. Between these hard layers are frequently found layers of soft or earthy matter.

Nothing definite is known in regard to the loss of heat caused by scale on heating surfaces, for there are too many circumstances to be considered to admit of exact calculation. It has been stated that a layer $\frac{1}{16}$ inch thick in the tubes of multitubular boilers is equivalent to a loss of from 15 to 20 per cent of fuel. The loss increases rapidly with the thickness of the scale. A uniform coating of scale is not nearly so harmful as irregular deposits, for in the latter case the evil effects of overheating are likely to be produced, and overheating will result where it is least suspected.

Prevention. *Chemical Precipitation.* Incrustation may be prevented by precipitating the scale-forming substances before the feed water reaches the boiler, by the introduction of chemical compounds to neutralize the evil effects, or by removing the sediment before it becomes hard.

Removal by Hand. Scale may, of course, be removed by hand from the interior of the boiler, but this is a slow and tedious process. One of the chief objections to removing scale by hand is that the surfaces of the boiler are likely to become abraded by the chipping tools, and this offers excellent opportunity for pitting and local corrosion to set in.

Turbine Tube Cleaners. Scale deposits on the heating surface of boilers give rise to the design and use of many devices for the removal of scale by mechanical means. When dealing with water-tube boilers, as the scale is deposited on the inside of the tube, the device can usually be applied directly on the deposit and the affected surface thoroughly cleaned. The device employed is generally an air-, steam-, or water-driven turbine which, in rotating, swings arms bearing cutters against the scale and interior tube surface. When a fire-tube boiler is to be cleaned of scale, the process is either to scrape it off by hand or to knock it off by inserting a water- or steam-driven rotating turbine hammer on the inside of the tube.

Fig. 39 illustrates a turbine cleaner suitable for water-tube boilers. This cleaner is water driven, the rotating effect being obtained by the reaction of the blades—shown just within the cylindrical head—when water under pressure is delivered by means of a hose to the opposite end of the head. The cutters are carried on arms which are pivoted on pins carried on the central spindle; thus the cutter arms are thrown outwardly by centrifugal force.

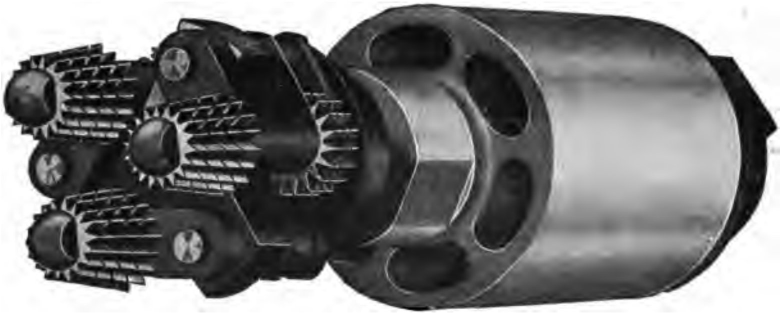

Fig. 39. "Weinland" Turbine Cleaner
Courtesy of The Lagonda Manufacturing Company, Springfield, Ohio

Contraction and Expansion. Scale has sometimes been removed by blowing the boiler off at comparatively high pressure, and then filling it with cold water. This causes a severe contraction of the plates, and is likely to loosen the scale; but it will at the same time cause serious injury to the boiler, and is a practice that should not be tolerated.

Blow-Out Apparatus. After the impurities are deposited in the boiler, the soft precipitates may be removed through the blow-out apparatus. When a boiler is let down it should be cooled slowly, and then the water may be drawn off and the boiler properly washed and scraped. A considerable amount of heat is abstracted from the boiler by frequent blowing off, and this is a matter of direct loss, but the loss is not as great as that caused by the formation of scale.

Boiler Compounds. Water may be purified to a certain extent by passing it through a purifier before allowing it to enter the boiler. The carbonate and sulphate of lime are precipitated at the same time that the water is heated. The purifier was referred to under the topic of "Feed-Water Heaters". The use of soda for the neutralization of sulphate of lime has already been spoken of; but various compounds are on the market for overcoming the evil effects of other solids; and it is possible, by an analysis of the feed water, to prescribe a boiler compound that will give satisfactory results. Cheap compounds, sold without reference to the analysis of the feed water, should be avoided. Caustic soda may be used instead of the carbonate but should be used in small quantities. A rapid circulation of the water will prevent the formation of scale, the sediment being swept from the tubes or shell into the mud drum, whence it may be blown off. This is one of the chief advantages claimed for water-tube boilers.

Electrolytic Action. Zinc plates have been used frequently to prevent corrosion and incrustation. The brass fittings are likely to set up a galvanic action with steel plates; but if the zinc is put in, it will be acted upon instead of the iron, which otherwise might be rapidly wasted. It is claimed that this galvanic action prevents the formation of scale by liberating hydrogen at the exposed surfaces. The zinc neutralizes the free acids, by combining with them, and takes the place of iron in causing precipitation of copper salts when present.

BOILER EXPLOSIONS

Safety the First Requisite in Design and Care of Boilers. Safety is one of the first requisites in a steam boiler and must be assured not only by proper design in the beginning but by subsequent care and proper maintenance. Since the explosion of a boiler, especially in a city or a factory, is likely to prove fatal to many people and to cause the destruction of considerable property not only by the explosion itself but also by the fire which almost invariably follows such an occurrence, too great emphasis cannot be laid on the boiler being in proper working condition.

Strictly speaking, failure of a pressure part of a boiler constitutes an explosion, provided the failure is such as to release steam and water from its natural confinement. There are literally hundreds of explosions every year in the United States, the term being used in the sense just given; many of them are of little pecuniary importance though the inconvenience may be considerable. On the other hand, the aggregate of losses sustained by owners during a year by reason of minor explosions is astonishing and quite important. These failures differ in magnitude only from the more serious explosions having the same causes and the same preventives.

Boiler Inspection. All boilers must be carefully tested—land boilers, by the State inspectors; marine boilers, by the United States inspectors. The boilers are carefully examined inside and outside and subjected to a hydraulic pressure test 50 per cent greater than the designed pressure of steam; and if there is the slightest sign of pitting or corrosion, the boiler plates may be drilled and the thickness calipered, the hole being refilled by a proper plug. If a boiler passes inspection, a subsequent explosion will probably be the result of mismanagement, although inspection is not infallible.

The owner of the boiler is usually held liable, in case of explosion, but may protect himself from financial loss by insurance against accident in any of the boiler insurance companies. If so insured, the insurance inspector, as well as the state inspector, examines the boiler; and there is consequently less likelihood of an explosion, for an insurance inspector will naturally be exceedingly careful in the interests of his company.

Nature of Explosions. The damage done by an explosion is due to the energy stored in the hot water, which energy can be calculated by thermodynamic methods. If a boiler contains a large quantity of water at high pressure, and that pressure is suddenly relieved, as would happen in case of rupture, a considerable portion of this large volume of water will be turned instantly into steam and an explosion will result.

When a fracture starts in a boiler plate, the steam escaping through the rent or opening tends to diminish the pressure rapidly within the boiler; and this causes the rapid formation of a large amount of steam. It must be remembered that the water in the boiler at high pressure is held in the form of water only because of the high pressure exerted on it. If this pressure is relieved, large quantities of water will evaporate into steam at once, without the application of further heat. The larger the body of hot water, the greater the disaster. This accounts for the relative safety of water-tube boilers. The division of the water in such a boiler into small masses in different sections, prevents a violent explosion. Should a water tube burn out, probably nothing more serious would happen than the rapid escape of a considerable quantity of steam, which might fill the boiler-room, drive out the attendants, and ultimately cause the destruction of the boiler because of the absence of water and the presence of a hot fire. It would be necessary for several water tubes to burst at once in order to cause serious damage from such an accident. Drums of water-tube boilers may, of course, fail the same as any other shell.

Energy Developed in an Explosion. The available energy in one pound of hot water at 150 pounds absolute pressure and 358° F., is about 42,800 foot-pounds; that is, it is sufficient to move one pound nearly eight miles; and if at 250 pounds pressure, it has sufficient energy to move it nearly twelve miles. This energy may be determined in the following manner: From the table of the properties of saturated steam, given in the back of the book, it is seen that at 150 pounds absolute pressure (approximately 135 gage), the temperature is 358.5° F. The heat above freezing temperature contained in a pound of hot water at this temperature will be 330 B.t.u., equivalent to 330×778, or 256,740 foot-pounds. This represents the total heat energy in one pound of hot water at boiler pressure; but since one pound of steam at atmospheric pressure contains very many more heat units than a pound of water at 150 pounds pressure, it is apparent that only a portion of this water can evaporate into steam, the remaining portion continuing as hot water. About 17 per cent of the total energy will be thus available in vaporizing the water into steam; or, approximately, 42,800 foot-pounds per pound of water will be developed. The remaining heat is contained in the hot water.

A cylindrical boiler 5 feet in diameter and 16 feet long is likely to contain about 6,600 pounds of water and 22 pounds of steam. Neglecting the energy of the steam, which is relatively small, the energy in the water due to its expansion from water at boiler pressure into steam at atmospheric pressure will be approximately 6,600×42,800 or 282,480,000 foot-pounds, or 141,240 foot-tons.

A marine boiler 13 feet in diameter and 12 feet long would develop approximately twice this energy, which would be about equivalent to the energy developed by the explosion of a ton of gunpowder. The explosion of one boiler on a modern battleship would develop sufficient power to lift the ship completely out of the water. Of course it must be realized that a large part of this energy is not applied to any moving part of the boiler, and considerable is consumed in the destruction of the boiler itself, which leaves but a comparatively small amount to be expended in wrecking the immediate surroundings; but, nevertheless, it is a fact that the energy developed in the explosion of a large boiler is almost beyond the power of comprehension.

Causes of Explosions. *General Discussion of Causes.* Boiler explosions are usually the result of low water, or the presence of grease or scale. The two latter, by preventing the transmission of heat from the water, are likely to cause undue overheating of the furnaces or tubes, which may result in their collapse; these two causes—grease and scale—have been discussed under the subject of "Incrustation".

Low water may be caused by failure of the water glass to indicate properly the amount of water in the boiler, or by failure of the feed pump to work properly.

Safety valves have been known to be rusted to their seats so tightly that they failed to work at the proper time.

It is seldom that a boiler can fail as the result of defective design, for the laws in regard to construction, especially of marine boilers, are very definite. Defective workmanship or material, however, cannot be easily discovered; and it is possible that corrosion or incrustation may take place locally without being readily detected; and, indeed, boiler plates may even be tapped, and their thickness calipered, without discovering small local weaknesses which later may cause disaster. Minute fractures which escaped the inspector's detection have later become serious. Without doubt, however, the majority of explosions can be traced to mismanagement in either care or operation.

Defective Design. If a boiler is improperly set, or if the stays are too small, too few, or cut or bent to clear floats, pipes, etc., danger is likely to result therefrom. All manholes, large handholes, or domes should be strengthened with a reinforcing plate to make up for the material cut out. If the boiler is set too rigidly on its seating, without proper provision for its expansion, trouble will probably follow. A defective water circulation is likely to cause excessive incrustation and unequal expansion of the plating, which is liable to open seams and produce fractures in the plates.

Deterioration. The strength of a boiler is likely to be impaired by fractures, general corrosion, pitting, or grooving, but external corrosion is the cause of many disasters. It proceeds unnoticed in many cases, and rupture may occur when least expected. In the discussion of "Corrosion", it was shown that improper setting of the boiler would cause, or at least aggravate, external corrosion; and that, on account of the close setting of the boiler, it was not easy to get at the plates to examine them. The strength of a boiler originally sufficient to sustain high pressure may become suddenly reduced by overheating or overstressing, either of which weakens the plates. Overheating may be caused by poor circulation, lack of water, or the accumulation of sediment or scale. Overstressing is caused by sudden cooling and contraction, or equally by sudden expansion. In starting the fire in a Scotch boiler—or, in fact, in any boiler with a large quantity of water—care must be taken that the fire is started slowly, or the boiler, becoming overheated locally, will develop excessive stresses.

Defects of Workmanship. Defective workmanship does not occur so frequently under present conditions as formerly, when many defects used to be produced by the careless punching of plates; but for most boilers, and for all marine boilers at present, punching rivet holes to size is prohibited; the holes are drilled in the solid plate, and the plate edges planed and carefully calked; or are punched small, then reamed or drilled with adjacent sheets tacked in position as when assembled. A rigid inspection of material is required, and there seems little danger of unsatisfactory work. Cheap boilers may, of course, be subject to various defects, but a good boiler should be free from such troubles. Defective material may be used and this may not be readily detected; but careful tests reduce these possibilities to a minimum.

Mismanagement. The pressure in a steam boiler may rise above that at which the safety valve has been set to operate, because of corrosion or overloading of the valve. Stop valves are sometimes placed between the boiler and the safety valve; but this practice should be condemned, as it is possible that the stop valve may be closed when the fireman thinks the safety valve is open to the boiler pressure. If the size or lift of the safety valve is too small, steam may be generated faster than it can escape, in which case the pressure will rise in spite of the safety valve. It has been claimed that the blowing off of the safety valve when the boiler is under excessive pressure may be the cause of starting an explosion; but the reason why this should be so does not seem to be especially clear, and it seems to be improbable, if the opening of the safety valve is sufficient to cause a reduction in pressure. Safety valves have sometimes been loaded down temporarily to prevent leakage at working pressure; but such a practice is little short of criminal. If a safety valve leaks, it should be reground, but under no circumstances should the weight on the lever be altered.

Effect of Sudden Influx of Water on Hot Plates. It is a common idea that when the furnace plates become very hot, perhaps heated to redness, due to a lack of water, and the feed is turned on, a violent explosion is sure to follow. Experiments show that when a piece of wrought iron is heated to redness and plunged into a weight of water three or four times greater than that of the iron, a comparatively small quantity of steam is disengaged. There is no reason to believe that this quantity would be greater if the iron were in the form of a boiler than in the form of a plate. If a small quantity of water should be admitted to the hot plates, the danger would be greater; and, while a boiler under this condition might explode, the comparatively small quantity of water in it would make the resulting danger much less than it would if the boiler were under working conditions.

The following experiments illustrate the action of cold water on hot plates. A boiler 25 feet long and 6 feet in diameter was heated red hot and the feed turned on. No explosion occurred; but the sudden contraction of the overheated plates caused the water to pour out in streams at every seam and rivet hole as far as the fire mark extended. In another instance, the water was almost entirely drawn off while the fires were burning briskly. When the remaining water had been converted into steam and all the fusible plugs melted out, water at the rate of 28 gallons per minute in a series of fine jets was played on the hot plates. Such treatment may ruin a boiler for further service, although the boiler may not explode.

That a tough paper or cloth is easily torn when once a tear is started is a well-known fact. Similarly a boiler plate may be ruptured at slight pressure if a fracture has been started.

Influence of Position of Fracture on Results of Explosion. The position of the fracture or hole has a great influence on the results. In case a large rent occurs at the top of a cylindrical boiler, the steam and hot water may blow out of the hole; and the boiler, if strongly enough seated to stand the reaction, will remain on its seat. The damage to the boiler would be slight. But if the same rent were situated on the under side of the boiler near the ground or floor, the effect would be very different. The reaction of the escaping steam would probably blow the whole boiler through the roof.

Investigation of Explosion. When an explosion occurs, it should be investigated, not only to fix the responsibility where it belongs, but also to provide for and take means to prevent future disasters. It has been customary to attribute all explosions to low water, since it is an easy way to throw the responsibility from the makers or owners upon the fireman, who, even if living, cannot defend himself. In the investigation of an explosion, the weights, shapes, positions, and directions of the scattered pieces should be noted, so that their original places may be known. The original size and shape of the boiler and of the fittings should be ascertained as accurately as possible. The primary rent may be discovered from comparison and from deductions of the directions taken by the heavier pieces. Light pieces will generally take the direction of the escaping steam, while the heavy parts take an opposite direction—that of the reaction. A careful examination of the pieces, noting the age of fractures, thickness of plates, amount of corrosion, condition of plates, etc., will generally show the cause. A test of the plates will in many cases show a softening or yielding to the pressure and excessive thinness caused by bulging.

Preventive Measures. The means taken to prevent boiler explosions from most of the previously mentioned causes have already been given. It is of primary importance that at the start only a well-designed and well-made boiler should be used. The matter of type is not of so much importance; but it is well to use a water-tube boiler in large cities or in buildings where many people are employed. There are many methods, some of which have been discussed, that are taken to prevent deterioration by corrosion, fracture, etc. Proper setting is of great importance in this matter. Mishaps from mismanagement may be greatly lessened by the employment of licensed attendants. A boiler should never be in the hands of a man who is not thoroughly competent to run it. The most effective method to prevent explosions is the law of the State, compelling regular, thorough inspection and licensed firemen. The inspection by the boiler insurance companies is also an efficient method.

During a period of eleven and one-half years, 70,000 boilers were inspected by boiler insurance companies. It was estimated that there were 140,000 in use during that time. Of the inspected boilers, there were 23 explosions and 50 collapses, resulting in 27 deaths from explosions, and 28 deaths from collapses. The accident rate was 1 in 10,000; and the death rate, 1 in 13,000. The uninsured boilers did not make so good a showing, the death rate being 1 in 5,000 boilers, or nearly 3 times as high as among the insured boilers.

SMOKE PREVENTION

Essence of Cure for Smoke. For a detailed explanation of the principles entering into the subject of smoke prevention the student is referred to the Instruction Paper, "Chemistry of Combustion", and to the several other works intended to cover the topic fully. The natural laws pertaining to the subject have been well-known for many years and, while they have been variously stated by different writers, their substance can be expressed briefly in the following words:

"Any fuel can be burned economically without the creation of smoke, provided sufficient air is mixed with the burning gases at a high enough temperature to maintain combustion, and provided time for the progress of the combustion process is afforded while the temperature is sustained."

This simple statement includes every phase of an otherwise perplexing subject. Every device used for the prevention of smoke either assists in fulfilling some feature of the requirements mentioned above, or it can have no useful purpose toward reducing smoke.

Brief Discussion of Preventive Devices. *Mechanical Stokers, Steam Jets, etc.* The uniform charging of fuel is one of the means of making it simpler in other respects to prevent smoke. It is in this way that mechanical stokers offer the greatest assistance in preventing smoke. The construction of fire-brick arches assist by affording mixing facilities, and by creating high-temperature chambers in which the gases can burn before encountering the comparatively cool surfaces of the boiler. Steam jets aid by intimately mixing the air with the gases, performing this function in a purely mechanical way. The introduction of air, either automatically or manually, over freshly charged fuel, as in hand-fired furnaces, makes it more easily possible for the carbon particles, which would otherwise escape as smoke, to seize their required quota of oxygen.

No Single Cure Entirely Successful. To approach the matter of smoke prevention intelligently requires that a full understanding of materials and fuels shall be available. By merely providing one of the necessary elements of success there is the danger that some equally important requirement may be overlooked. To illustrate this point, it is only necessary to say that it is easily possible to arrange for the admission of entirely too much air into the combustion chamber, with the effect that the temperature of the whole space may be reduced below a desirable point, and then the results may be very unsatisfactory. In other words, enough air is quite desirable, but it is easy to exceed the desirable quantity. Even though such means might solve the smoke problem in one particular instance, the result might still be economically bad.

The construction of fire-brick piers and arches may be carried out to such an extent that serious restrictions to the gases are created, and the available chimney will in that case fail to supply the required amount of air through the fuel bed. There is the possibility, also, that the gain from the use of complicated and expensive arches may be more than offset by the cost of keeping them intact.

Effect of Municipal Regulations. The public, in large cities especially, are demanding that smoke shall be avoided, and in several notable instances, especially in Chicago, Milwaukee, Cleveland, and Detroit, the smoke bureaus of the city governments have educated groups of men who have specialized in the art of smoke prevention. Wherever it becomes obligatory to comply with a city regulation aimed against smoke, the means taken in the community to accomplish the desired end can be explained by the officials of that community. It is well to remember that the means which are successful in one locality are not necessarily so in another. The difference arises from the difference in fuels.

FUELS AND FUEL ECONOMY

HEAT VALUE OF FUELS

There are various kinds of fuel used in steam production, location, cost, and the exigencies of the case being the deciding factors. Usually the kind of fuel is determined upon, and the boiler designed for its use. Sometimes, however, the fuel must be adapted to the boiler.

Coal. Coal is not only the most important fuel, but in many localities the only one available. It is of vegetable origin, being the long-decayed product of ancient forests. Frequently it occurs so mixed with earthy matter as to be of little value; but the supply of good coal is still abundant, and likely to be so for many years to come.

The most important elements in coal are hydrogen, producing 62,000 B.t.u. per pound, and carbon, producing 14,500 B.t.u. per pound. Although several coals may have the same total percentage of combustible material and ash, the heat values may not be the same, because heat value depends upon the amounts of available hydrogen and carbon they contain. The heat value of fuel is determined by chemical analysis, or by calorimetric test, and varies for coals from different localities. Table I is compiled from several sources.

In practice, no fuel delivers results up to its theoretical evaporation value. On account of several losses which are inevitably incurred, all of the available heat of the fuel is not converted into

TABLE I

Analyses and Heat Values of Various Coals

Kind of Coal	Per Cent of Ash	B.t.u. Per Lb. Dry
Penn. Anthracite, Large	5.97	13720
Penn. Anthracite, No. 1 Buckwheat	11.60	12100
Penn. Semi-Anthracite	11.47	13547
W.-Va. Semi-Bituminous, Mine Run	5.57	14959
Ala. Bituminous, Mine Run	10.70	13628
Ill. Bituminous, Franklin Co., Egg	11.43	11727
Ill. Bituminous, Macoupin Co., Mine Run	12.42	10807
Ind. Bituminous, Brazil Co., Block	8.00	13875
Ind. Bituminous, Knox Co., Mine Run	9.79	12911
Iowa Bituminous, Lucas Co., Mine Run	15.94	11963
Kan. Bituminous, Cherokee Co., Lump	12.45	13144
Ky. Bituminous, Hopkins Co., Mine Run	10.77	13036
Colo. Lignite, Boulder Co	9.91	10678
N. Dak. Lignite, McLean, Lump	12.11	11036
Tex. Lignite, Wood Co	11.63	10600
Wyo. Lignite, Crook Co	8.37	12641

energy in the steam. The admission of too much air into the furnace, either through the doors or through cracks in the setting, reduces the actual evaporation. Improper firing causes considerable loss; and errors in design, construction, or setting of furnaces and boilers all contribute to the losses.

The different kinds of coal are too numerous to be easily named, but in general they may be classified as anthracite or bituminous, commonly called hard or soft, respectively, of which there are various subdivisions.

Anthracite. Anthracite coal consists mainly of carbon, with a small amount of hydrocarbon and considerable ash. Good anthracite is lustrous, hard, and flinty, but breaks up easily under high temperature. It burns with very little flame and smoke and gives an intense heat. It does not ignite so readily as the softer varieties of coal but, once started, the fire requires less attention. It is an excellent fuel where the production of smoke is a decided objection.

Semi-Anthracite. This is a coal between pure anthracite and semi-bituminous. It is not so hard as anthracite and burns more freely. It is not so compact as anthracite and burns with a short flame, the anthracite having practically no flame.

Semi-Bituminous. This is the next softer grade of coal. It burns more freely than either anthracite or semi-anthracite, contains more volatile hydrocarbon, and is a valuable coal for steaming purposes. The ash content is low and its heat value high. It is lustrous and has a very granular fracture.

Bituminous. Bituminous coal forms by far the larger portion of steam coal. It contains a large but varying amount of hydrocarbon or bituminous matter. Unless fired with care, it will produce a considerable amount of smoke and clinkers.

Dry Bituminous. This is a black coal with a resinous luster. It burns freely, and kindles with much less difficulty than the anthracites. It is hard, but is easily splintered. When burning, it gives a moderate amount of flame, with but little smoke, and does not cake. It is found chiefly in Maryland and Virginia.

Caking Bituminous. This contains less carbon and more hydrocarbon than the former class. It is not so black; is more resinous; and, under intense heat, readily forms into a solid, pasty mass. Unless frequently broken up, this pasty mass forms a blanket over the grate, and checks the air supply. Caking bituminous is a valuable coal for the manufacture of gas. It is mined chiefly in the Mississippi Valley.

Cannel. Cannel, or long-flame bituminous coal, produces a considerable quantity of smoke. It is mined chiefly in Pennsylvania, Indiana, and Missouri; and is a free-burning coal, with a strong tendency to cake. It is largely used for open-grate purposes.

Lignite. Lignite, or brown coal, is intermediate between coal and peat. It is made up mostly of carbon, with a large percentage of moisture and some mineral matter. Poor varieties are of little value. Good lignite kindles with ease, and burns freely. It is not a very good fuel, but is used in some localities where other varieties are more expensive. It comes largely from Colorado, Texas, Washington, and the Dakotas.

Peat. This is a form of fuel consisting of decayed roots, tree-trunks, etc., and earthy matter. It is found in swamps and bogs, and has been in process of decomposition a much shorter time than any of the coals. It is cut out in blocks and dried. Peat has a specific gravity of .4 to .5, but it can be compressed to a much greater density. It is necessary that peat should be kept in a dry place, for it will readily absorb moisture.

Coke. Coke is made by driving off by heat the hydrocarbon of bituminous or semi-bituminous coals. It may be made in gas retorts, as a by-product of gas production; or it may be made in coking ovens, the gas being the by-product. The latter form of coke is more valuable as a fuel. If the coal is very moist, or if steam is used in the coking process, as in the manufacture of water gas, the sulphur is burned out. Coke burns without flame, and, with a free supply of air, will make an intensely hot fire.

Charcoal. Charcoal is practically never used for steam fuel, its chief use being for household or manufacturing purposes. It is made by evaporating the volatile matter from wood, either by partial combustion or by heating in retorts. About 50 bushels of charcoal can be obtained from a cord of wood.

Culm. This is a name given to refuse dust at the coal mines, sometimes called slack. It can be bought at the mines at a very low rate; but the cost of transportation prohibits its use except in the immediate vicinity of the mines. On account of its fineness, it cannot be burned on an ordinary grate, and is sometimes blown into the furnace with a sufficient quantity of air, where it burns somewhat like a gas. A grate beneath usually contains a moderate fire, which keeps the culm well ignited and prevents the loss of any particles that might otherwise drop out of the furnace.

Wood. There are two principal divisions of wood—hard wood, which is compact and comparatively heavy, such as oak, ash, and hickory; and soft wood, which is of soft and porous texture and of less specific gravity, such as pine, birch, and poplar. Wood contains considerable moisture, even if left to season in a dry place; and after being thoroughly dried, it will absorb and retain from 10 to 20 per cent of moisture. Kiln-dried wood contains nearly 8000 B.t.u. per pound, while the average wood which contains about 25 per cent of moisture, has a heating value of about 6000 B.t.u.

The chemical composition of different woods is nearly the same, and, pound for pound, one class of wood contains about the same heating value as another. Pine weighs about half as much as oak per cubic foot, and a cord of such wood contains about half the heating value that a cord of oak would contain.

Sawdust and shavings are frequently used as fuel in sawmills and planing mills. This kind of fuel is blown into the furnace by air from a fan, and makes an intense heat. A fine grate at the bottom collects the burning embers, which might otherwise drop into the ash pan. In mills where sawdust and shavings are used, they are a by-product.

Straw. Threshing machines through the West use straw almost entirely for fuel. It gives an intense heat, furnishing 5000 to 6000 heat units per pound; and this is a quick and easy way to get rid of it.

Bagasse. Bagasse is the fibrous portion of the sugar cane left after the juice has been extracted. In the modern process of sugar manufacture, the cane is pressed so tightly that it is ready for fuel without further treating. Under favorable conditions it forms an excellent fuel. The pressed cane is a by-product which must in some way be got rid of. It is usually fed into the furnace through an automatic hopper; or it may be dumped in the fireroom and fed into the furnace by hand. The furnace is constructed of brick, independent of the boilers; and when bagasse is consumed at a high temperature, the oxygen contained in it is nearly sufficient to satisfy the carbon and hydrogen, so that little air from the outside is required. Such material, of course, cannot be fed into an ordinary furnace.

Liquid Fuels. These consist of petroleum and its products, and their use has become quite extensive in the last few years. The field would undoubtedly be wider were there less difficulty in obtaining a regular and constant supply. The greatest quantities of petroleum oil are produced in the United States and Russia. Large quantities are found on the Pacific Coast, especially in Southern California; and in that section of the country, oil is used as fuel to a greater extent than in the East, being largely used on tugboats, ferryboats, and locomotives.

The following, approximately, is the composition of petroleum:

Carbon	82 to 87 per cent
Hydrogen	11 to 15 per cent
Oxygen	$\frac{5}{10}$ to 6 per cent

The theoretical heat value of petroleum is approximately 20,000 B.t.u. per pound, which is nearly half as much again as that of good coal. Oil has a further advantage over coal, in that no unburned fuel necessarily passes through the furnace, and there is no ash—an important item in marine work.

TABLE II

Evaporative Power of Gases

QUANTITY	NATURAL GAS	COAL GAS	WATER GAS	PRODUCER GAS
Cubic feet of gas	1000	1000	1000	1000
Pounds of water evaporated	893	591	262	115

The composition and specific gravity of petroleums vary considerably, many of the lower grades being unsafe on account of their low flash-point.

Gas. Gas has many advantages over any other kind of fuel. There are four different varieties—natural gas, coal gas, water gas, and producer gas. Natural gas is used largely in the vicinity of Pittsburgh, Buffalo, and some parts of Indiana, both for illuminating and for steam purposes. Where natural gas is plentiful, it is by far the cheapest fuel that can be used.

Coal gas, made by the distillation of coal, and water gas, obtained by the decomposition of steam by incandescent carbon, have been used both for lighting and for fuel; but in most cases these gases may be used to greater economy directly in the cylinder of a gas engine than as fuel under a steam boiler. The same may be said of producer gas, which is made by blowing steam and air through incandescent coal.

The relative values of these gases for evaporation are shown in Table II.

Experiments in Pittsburgh have shown that 1000 cubic feet of natural gas equals 80 to 133 pounds of coal. The coal used in the comparison varied from 12,000 to 13,000 B.t.u. per pound.

The Western Society of Engineers has stated that one pound of good coal is equivalent in heating value to 7½ cubic feet of natural gas.

As in the case of petroleum, the economy of burning gaseous fuels depends upon the locality.

Artificial Fuels. Waste charcoal, coal, or wood sawdust are frequently compressed into briquettes in which pitch or other adhesive substances form the binder. When properly made, they can be stored and handled in a very satisfactory manner, often being of better fuel value than the base fuel which enters into the manufacture. Briquetting has not thus far been extensively resorted to because the natural fuels have been plentiful enough to obviate the necessity of employing the reclaiming of waste fuels which affords the best reason for resorting to this form of fuel manufacture. However, it is certain that for domestic use, at least, briquetted fuel will become increasingly familiar. In this field briquettes offer an ideal fuel, being attended by no new burning difficulties while overcoming the customary disadvantages of dust, smoke, soot, and clinkers, where the natural fuels are unsatisfactory in these particulars.

Pulverized Coal. As a result of extensive progress in cement manufacture where pulverized coal found its first successful large application, the general use of pulverized coal has improved to a large extent in other directions so as to displace gas and oil in special metallurgical furnaces and in connection with steam generation. In the field of steam engineering the installations are thus far relatively few, but the art of using coal in this form for that purpose is now understood in all of its main aspects, while the results prove to be economically good enough to warrant the cost of preparation.

It has been known for many years that pulverized coal could be burned in very much the same way that oil is burned, but a few elements were not fully appreciated as to their importance, thus operating against a wider use of this system of fuel burning.

The steps of main importance where pulverized coal is prepared and burned include the following:

(1) A receiving hopper from which the natural coal is conveyed to a crusher and thence moved to a storage bin.

(2) A magnetic metal removing device to take foreign metal parts out of the coal to be pulverized.

(3) Drying crushed coal to less than 1 per cent of moisture preparatory to pulverizing to a fineness of 85 per cent through a 200-mesh screen.

(4) The mechanical conveyance to a pulverized coal bin and from thence as needed in measured quantities to the burner head.

(5) The introduction of fan-driven air of correct quantity carrying the pulverized coal in suspension into a fire-brick combustion chamber.

(6) Facilities for the precipitation of slag and its removal from the furnace chamber.

(7) Contrivances for adjusting the rates of coal and air delivery and varying the furnace draft so as to carry the burning gases out of the furnace and through the boiler setting.

In connection with all these items, it must be considered that pulverized coal is highly inflammable when air quantities are correct for its combustion and carrying more than 1 per cent of moisture cannot easily be screened or moved mechanically.

BOILER PERFORMANCE

HORSEPOWER OF BOILERS

Boiler Horsepower Unit. The unit which we call boiler horsepower is arbitrary. This unit for boilers has been adopted on the assumption that 30 pounds of steam are required per horsepower per hour for an average engine.

One boiler horsepower is the evaporation of 30 pounds of water per hour, from a temperature of 100° F. into steam at 70 pounds gage pressure. This is practically equivalent to the evaporation of 34½ pounds per hour from and at 212° F.

Significance of Boiler Horsepower. Strictly speaking, the term boiler horsepower is a misnomer, for the factor it is usually intended to represent is not power at all. The reader who understands the exact physical significance of the term *energy* will recognize that boiler horsepower is really a term applied to the amount of energy transfer or absorption, the original source being the energy released by the burning of fuel. Common use fixes the meaning of the phrase so no serious difficulty results.

It is also well to distinguish clearly the difference between boiler horsepower and the still more inexact term *size of a boiler*. The former has to do with something that actually occurs, while the latter refers to the probable ability of the boiler to deliver a performance under average conditions. It is best to use the expression boiler horsepower *rating* in the latter case.

As all boilers do not generate steam at the same pressure and from the same temperature of feed water, it is necessary to reduce the actual evaporation to an equivalent evaporation. Unless this is done, the relative performances of boilers cannot be compared.

For this comparison, the actual evaporation is reduced to the equivalent evaporation from and at 212° F., that is, we suppose the water to be fed at 212° F. and evaporated into steam at 212° F.

Let W be the water actually evaporated in pounds; H, the total heat of steam above 32° F., at actual absolute pressure; T, the temperature of feed water; and w, the equivalent evaporation from and at 212° F.

Since 970.4* B.t.u. are necessary to evaporate one pound of water from and at 212° F., the equivalent evaporation may be found from the formula

$$W(H+32-T)=970.4w$$

or

$$w=\frac{W(H+32-T)}{970.4}$$

Then the horsepower of the boiler is

$$\text{h. p.}=\frac{w}{34.5}$$

The above method is considerably shortened by substituting for the quantity $\frac{H+32-T}{970.4}$, the number found in Table III, which corresponds to the actual feed-water temperature and steam pressure.

For example, a boiler is required to furnish 2100 pounds of steam per hour. If the gage pressure is 80 pounds, and the feed water enters at 50° F., what is the equivalent evaporation, and what is the horsepower?

From Table III, the factor for 80 pounds pressure and 50° F. is 1.2028. Then the equivalent evaporation would be 1.2028×2100, or 2525.9 pounds; and $\frac{2525.9}{34.5}$ equals 73 (approximate) horsepower.

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*This value is taken from Marks and Davis' "Steam Tables and Diagrams", now commonly accepted (1918).

TABLE III

Factors of Evaporation

Taken with permission from Marks and Davis' "Steam Tables and Diagrams", published by Longmans, Green and Company

Feed Temperature Degrees Fahrenheit	Steam Pressure by Gage															
	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
32	1.2143	1.2170	1.2194	1.2215	1.2233	1.2251	1.2265	1.2280	1.2292	1.2304	1.2314	1.2323	1.2333	1.2342	1.2350	1.2364
40	1.2060	1.2087	1.2111	1.2131	1.2150	1.2168	1.2181	1.2196	1.2209	1.2221	1.2231	1.2241	1.2250	1.2259	1.2267	1.2274
50	1.1957	1.1984	1.2008	1.2028	1.2047	1.2065	1.2079	1.2093	1.2106	1.2117	1.2128	1.2137	1.2147	1.2156	1.2164	1.2171
60	1.1854	1.1881	1.1905	1.1925	1.1944	1.1961	1.1976	1.1990	1.2003	1.2014	1.2025	1.2034	1.2044	1.2053	1.2061	1.2068
70	1.1751	1.1778	1.1802	1.1822	1.1841	1.1859	1.1873	1.1887	1.1900	1.1911	1.1922	1.1931	1.1941	1.1950	1.1958	1.1965
80	1.1648	1.1675	1.1699	1.1720	1.1738	1.1756	1.1770	1.1785	1.1795	1.1809	1.1819	1.1828	1.1838	1.1847	1.1855	1.1863
90	1.1545	1.1572	1.1596	1.1617	1.1636	1.1653	1.1668	1.1682	1.1695	1.1706	1.1717	1.1725	1.1735	1.1744	1.1752	1.1760
100	1.1443	1.1470	1.1493	1.1514	1.1533	1.1550	1.1565	1.1579	1.1592	1.1603	1.1614	1.1623	1.1633	1.1642	1.1650	1.1657
110	1.1340	1.1367	1.1391	1.1411	1.1430	1.1448	1.1462	1.1477	1.1489	1.1500	1.1511	1.1520	1.1530	1.1539	1.1547	1.1554
120	1.1237	1.1264	1.1288	1.1309	1.1327	1.1345	1.1359	1.1374	1.1386	1.1398	1.1408	1.1418	1.1427	1.1436	1.1444	1.1452
130	1.1134	1.1161	1.1185	1.1206	1.1225	1.1242	1.1257	1.1271	1.1284	1.1295	1.1305	1.1315	1.1324	1.1333	1.1341	1.1349
140	1.1031	1.1058	1.1082	1.1103	1.1122	1.1139	1.1154	1.1168	1.1181	1.1192	1.1203	1.1212	1.1221	1.1230	1.1239	1.1246
150	1.0928	1.0955	1.0979	1.1000	1.1019	1.1036	1.1051	1.1065	1.1078	1.1089	1.1099	1.1109	1.1118	1.1127	1.1136	1.1143
160	1.0825	1.0852	1.0876	1.0898	1.0916	1.0933	1.0948	1.0962	1.0975	1.0986	1.0997	1.1006	1.1015	1.1024	1.1033	1.1040
170	1.0722	1.0749	1.0773	1.0794	1.0813	1.0830	1.0845	1.0859	1.0872	1.0883	1.0893	1.0903	1.0912	1.0921	1.0930	1.0937
180	1.0619	1.0646	1.0670	1.0691	1.0709	1.0727	1.0741	1.0756	1.0768	1.0780	1.0790	1.0800	1.0809	1.0818	1.0826	1.0834
190	1.0516	1.0543	1.0567	1.0587	1.0606	1.0624	1.0638	1.0653	1.0665	1.0676	1.0687	1.0696	1.0706	1.0715	1.0723	1.0730
200	1.0412	1.0439	1.0463	1.0484	1.0503	1.0520	1.0535	1.0549	1.0562	1.0573	1.0584	1.0593	1.0602	1.0611	1.0620	1.0627
210	1.0309	1.0336	1.0360	1.0380	1.0399	1.0417	1.0441	1.0446	1.0458	1.0469	1.0480	1.0489	1.0499	1.0508	1.0516	1.0523

Measurement of Moisture in Steam. Steam from a boiler is generally accompanied by more or less moisture. This, being mechanically suspended in the steam, cannot readily be measured without the use of special apparatus. An instrument by means of which the percentage of moisture in steam can be determined is generally called a calorimeter. There are several different types of this instrument, only three of which will be described.

Barrel Calorimeter. This was invented by the distinguished engineer, G. A. Hirn, and is not only one of the earliest of these devices, but is by all means the simplest and most inexpensive form of calorimeter in practical use. It is shown in Fig. 40. The essential apparatus consists simply of a barrel holding about 400 pounds of water, and scales for weighing. A pipe, with suitable connections leading from the boiler or steam main, conveys the sample of steam to be tested. This pipe should be provided with a valve, and on the end should be a piece of rubber hose which can be readily inserted in the barrel or removed. The principle of this calorimeter is extremely simple. As steam flows through the pipe, it is condensed by the water in the barrel, and the increase in the weight of the barrel after the test indicates the total amount of moist steam condensed, while the rise in temperature of the water in the barrel is an exact measure of the quantity of heat obtained from this moist steam.

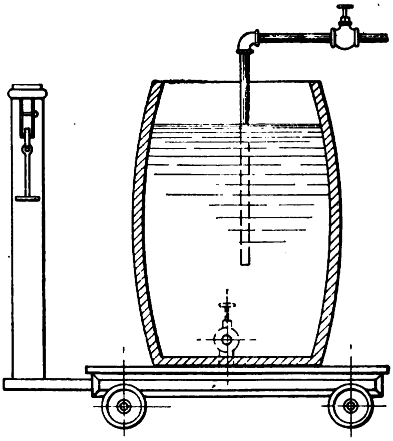


Fig. 40. Barrel Calorimeter

Table IV gives the number of B.t.u. in dry steam and hot water at various temperatures and pressures; and with this data and the previously mentioned observations made in the barrel, the percentage of steam and moisture can be readily determined.

The sampling pipe usually projects into the steam main a few inches, the end being perforated so that the sample will be drawn from a point near the middle of the pipe. An agitator should be

TABLE IV

Properties of Saturated Steam

Taken with permission from Marks and Davis' "Steam Tables and Diagrams", published by Longmans, Green and Company.

Pressure Pounds Absolute	Temperature Degrees F.	Specific Volume Cu. Ft. per Lb.	Heat of the Liquid B. t. u.	Latent Heat of Evap. B. t. u.	Total Heat of Steam B. t. u.	Pressure Pounds Absolute
2	126.15	173.5	94.0	1021.0	1115.0	2
4	153.01	90.5	120.9	1005.7	1126.5	4
6	170.06	61.89	137.9	995.8	1133.7	6
8	182.86	47.27	150.8	988.2	1139.0	8
10	193.22	38.38	161.1	982.0	1143.1	10
12	201.96	32.36	169.9	976.6	1146.5	12
14	209.55	28.02	177.5	971.9	1149.4	14
*14.7	212.0	.....	.....	970.4	......	14.7
16	216.3	24.79	184.4	967.6	1152.0	16
18	222.4	22.16	190.5	963.7	1154.2	18
20	228.0	20.08	196.1	960.0	1156.2	20
22	233.1	18.37	201.3	956.7	1158.0	22
24	237.8	16.93	206.1	953.5	1159.6	24
26	242.2	15.72	210.6	950.6	1161.2	26
28	246.4	14.67	214.8	947.8	1162.6	28
30	250.3	13.74	218.8	945.1	1163.9	30
32	254.1	12.93	222.6	942.5	1165.1	32
34	257.6	12.22	226.2	940.1	1166.3	34
36	261.0	11.58	229.6	937.7	1167.3	36
38	264.2	11.01	232.9	935.5	1168.4	38
40	267.3	10.49	236.1	933.3	1169.4	40
42	270.2	10.02	239.1	931.2	1170.3	42
44	273.1	9.59	242.0	929.2	1171.2	44
46	275.8	9.20	244.8	927.2	1172.0	46
48	278.5	8.84	247.5	925.3	1172.8	48
50	281.0	8.51	250.1	923.5	1173.6	50
52	283.5	8.20	252.6	921.7	1174.3	52
54	285.9	7.91	255.1	919.9	1175.0	54
56	288.2	7.65	257.5	918.2	1175.7	56
58	290.5	7.40	259.8	916.5	1176.4	58
60	292.7	7.17	262.1	914.9	1177.0	60
62	294.9	6.95	264.3	913.3	1177.6	62
64	297.0	6.75	266.4	911.8	1178.2	64
66	299.0	6.56	268.5	910.2	1178.8	66
68	301.0	6.38	270.6	908.7	1179.3	68
70	302.9	6.20	272.6	907.2	1179.8	70
72	304.8	6.04	274.5	905.8	1180.4	72
74	306.7	5.89	276.5	904.4	1180.9	74
76	308.5	5.74	278.3	903.0	1181.4	76
78	310.3	5.60	280.2	901.7	1181.8	78
80	312.0	5.47	282.0	900.3	1182.3	80
82	313.8	5.34	283.8	899.0	1182.8	82
84	315.4	5.22	285.5	897.7	1183.2	84
86	317.1	5.10	287.2	896.4	1183.6	86
88	318.7	5.00	288.9	895.2	1184.0	88
90	320.3	4.89	290.5	893.9	1184.4	90
92	321.8	4.79	292.1	892.7	1184.8	92
94	323.4	4.69	293.7	891.5	1185.2	94

*Atmospheric pressure. The latent heat value of 970 B.t.u. will be sufficiently accurate for use in this paper.

TABLE IV—Continued

Properties of Saturated Steam

Taken with permission from Marks & Davis' "Steam Tables and Diagrams", published by Longmans, Green and Company.

Pressure Pounds Absolute	Temperature Degrees F.	Specific Volume Cu. Ft. per Lb.	Heat of the Liquid B.T.U.	Latent Heat of Evap. B.T.U.	Total Heat of Steam B.T.U.	Pressure Pounds Absolute
96	324.9	4.60	295.3	890.3	1185.6	96
98	326.4	4.51	296.8	889.2	1186.0	98
100	327.8	4.43	298.3	888.0	1186.3	100
105	331.4	4.23	302.0	885.2	1187.2	105
110	334.8	4.05	305.5	882.5	1188.0	110
115	338.1	3.88	309.0	879.8	1188.8	115
120	341.3	3.73	312.3	877.2	1189.6	120
125	344.4	3.58	315.5	874.7	1190.3	125
130	347.4	3.45	318.6	872.3	1191.0	130
135	350.3	3.33	321.7	869.9	1191.6	135
140	353.1	3.22	324.6	867.6	1192.2	140
145	355.8	3.11	327.4	865.4	1192.8	145
150	358.5	3.01	330.2	863.2	1193.4	150
155	361.0	2.92	332.9	861.0	1194.0	155
160	363.6	2.83	335.6	858.8	1194.5	160
165	366.0	2.75	338.2	856.8	1195.0	165
170	368.5	2.68	340.7	854.7	1195.4	170
175	370.8	2.60	343.2	852.7	1195.9	175
180	373.1	2.53	345.6	850.8	1196.4	180
190	377.6	2.41	350.4	846.9	1197.3	190
200	381.9	2.29	354.9	843.2	1198.1	200

placed in the barrel, so that the water may be thoroughly stirred and a uniform temperature maintained during the test.

To test a sample of steam by this method, fill the barrel about two-thirds full of cold water; place it on platform scales, and carefully note its weight and temperature. The weight of the barrel and fittings, when empty, should of course be known, so that the weight of the water alone can be determined. With the hose removed from the barrel, allow steam to blow through the pipe until it has become thoroughly heated. If the sampling pipe is long, it should be wrapped with hair felt or some form of lagging, to prevent condensation during the test. As soon as the pipe line has become thoroughly heated, plunge the hose into the barrel and allow the steam to blow through the water until it has become well heated. Shut off the steam, and carefully note the weight and temperature.

Suppose W is final weight of water in barrel; w is weight of cold condensing water before steam is turned on; t_1 is temperature of the cold water; t_2 is temperature of the hot water; and P is absolute pressure of steam in steam pipe (gage pressure+atmospheric pressure).

From Table IV we find that q is the B.t.u. in one pound of the liquid contents of the moist steam; q_1 the B.t.u. in one pound of the cooling water, before the steam was added; q_2 is the B.t.u. in one pound of this water after the steam has been added; and r is the heat of vaporization corresponding to the absolute pressure—*i. e.*, B.t.u. given up by one pound of steam condensed into water.

If x equals the percentage of dry steam contained in the supply pipe, $1-x$ will represent the amount of priming; $x\ (W-w)$ equals the total amount of dry steam condensed; and $(1-x)\ (W-w)$ equals the total amount of moisture brought into the barrel by the moist steam.

If q_1 equals the heat in one pound of cooling water, then q_1w will equal the total heat in the barrel at the beginning.

For the same reason q_2W will equal the total heat after the steam has been condensed, and q_2W-q_1w will equal the total amount of heat gained by the water in the barrel.

If r is the heat of vaporization, then $rx\ (W-w)$ will equal the B.t.u. contained in the dry steam; and if q is the heat of the liquid corresponding to the same pressure, then $q\ (1-x)\ (W-w)$ will equal the B.t.u. contained in the moisture brought over by the steam. It is apparent that the sum of these two quantities will be the total number of B.t.u. brought from the steam main to the water barrel, and must be equal to q_2W-q_1w, the heat gained by the water in the barrel. The solution of this equation will result in a formula which will save some mathematical computations.

That the method may be perfectly clear, let us first consider a numerical example in full.

Example. Find the amount of dry steam and the amount of priming in one pound of moist steam.

Let w equal 455 pounds; W equal 495 pounds; t_1 equal 50° F.; t_2 equal 140° F.; P equal 75 pounds; and from Table IV q equals 277.4; q_1 equals 18; and q_2 equals 108. Then the total heat in the barrel after condensation is equal to

$$(495 \times 108) = 53{,}460 \text{ B.t.u.}$$

The total heat before condensation was equal to

$$455 \times 18 = 8190 \text{ B.t.u.}$$

Therefore, the heat brought over by the moist steam will be

$$53{,}460 - 8190 = 45{,}270 \text{ B.t.u.}$$

Now, from Table IV,

$$q = 277.4 \qquad r = 903.7$$

The heat given up by condensation of the dry steam will then be

$$903.7 \times (495 - 455)\, x = 40x \times 903.7 = 36{,}148x$$

And the heat of the liquid in the moisture and condensed steam will be

$$40 \times 277.4 = 11{,}096$$

Making the total heat in the moist steam equal 11,096 × 36,148x. Therefore,

$$\begin{aligned} 11{,}096 + 36{,}148x &= 45{,}270 \\ 36{,}148x &= 34{,}174 \\ x &= 0.945 \end{aligned}$$

That is, every pound of moist steam contains .945 pounds dry steam and .055 pounds moisture; or we may say there was 5.5 per cent of priming.

A formula for the above analysis may be derived by the following algebraic work:

Total heat in bbl. after condensation $= W q_2$
Total heat in bbl. before condensation $= w q_1$
Total heat brought over by steam $= W q_2 - w q_1$
Heat of liquid in condensed steam $= (W - w)\, q$
Latent heat in dry steam $= x\,(W - w)\, r$
Total heat in moist steam $= x\,(W - w)\, r + (W - w)\, q$

Therefore

$$\begin{aligned} x\,(W - w)\, r + (W - w)\, q &= W q_2 - w q_1 \\ x\, r\,(W - w) &= W q_2 - w q_1 - W q + w q \end{aligned}$$

or, transposing to a more convenient form

$$x = \frac{w\,(q - q_1) - W\,(q - q_2)}{r\,(W - w)}$$

The use of barrel calorimeter is not especially to be commended, for it is liable to error, and a slight discrepancy in the weights or the temperatures may cause a large error in the result. In the above calculations, no allowance is made for loss of heat by radiation.

Separating Calorimeter. This instrument, shown in Fig. 41, consists of a chamber A, into which is led a steam pipe D, bringing a sample of steam from the boiler or steam main. This pipe leads into an enlargement perforated with small holes, or into a chamber A as shown in Fig. 41. The calorimeter separates the moisture from the steam just as a steam separator does; and the exhaust, which is dry steam, passes out of the pipe P, wherein is inserted a diaphragm containing small orifices, by means of which the quantity of steam flowing out can be calculated by thermodynamic methods. The exhaust steam can, of course, be led to some form of condensing apparatus, if desired, and the amount of condensation found by weighing.

As the steam enters the calorimeter, the moisture is drawn toward the bottom of the chamber. The amount of water collected can readily be read from the gage glass at the side, to which a graduated scale should be attached.

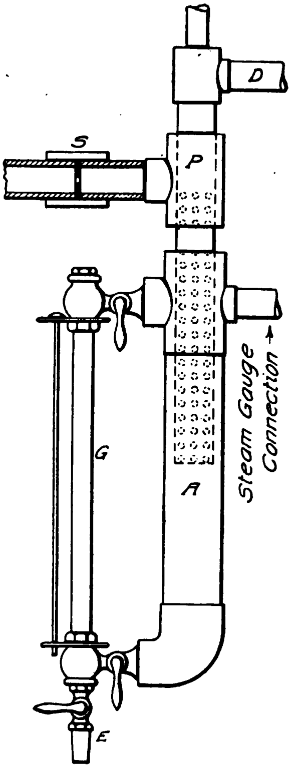


Fig. 41. Separating Calorimeter

The amount of moisture contained in the steam can be weighed directly by drawing it out of the gage cock E. The amount of dry steam is measured by its flow through the orifices, or by condensation. If W equals weight of steam discharged from the calorimeter, w equals weight of water collected and P equals percentage of priming, then

$$P=\frac{w}{W+w}$$

If only a small quantity of steam is used, an allowance must be made for condensation; but if the instrument is well lagged with hair felt or other suitable material, and a sufficient quantity of steam is used, the error from radiation may be neglected. Steam should be allowed to flow through the instrument until it has become thoroughly heated before beginning the test.

Throttling Calorimeter. This was invented by Professor Cecil H. Peabody, and is made with varying constructive details. Fig. 42 shows the general arrangement. The mixture of steam and water from the boiler is taken from the main steam pipe through what is termed a sampling pipe. Various forms of this pipe are made. One arrangement consists of a pipe closed at its inner end, but having numerous holes $\frac{1}{8}$ inch in diameter drilled staggered around the sides. The calorimeter should be placed as close as possible to the main steam pipe, and the gage for indicating the pressure in the main steam pipe should be placed on the latter and near the calorimeter. The gage is sometimes connected to a tee on the pipe leading to the calorimeter; but it is better to have this gage where the velocity of the flowing steam is less. A valve is placed in the pipe to the calorimeter, below which is inserted a nipple *A* having a small converging orifice *D*, about 0.2 of an inch in diameter and very carefully made. The object of such an orifice is to determine the weight of steam flowing through the calorimeter, so that an allowance may be made for the loss when testing an engine or boiler, where the net weight used is required. A cup *B* is screwed into the top, for holding an accurate thermometer. The cup is made of brass, and is filled with

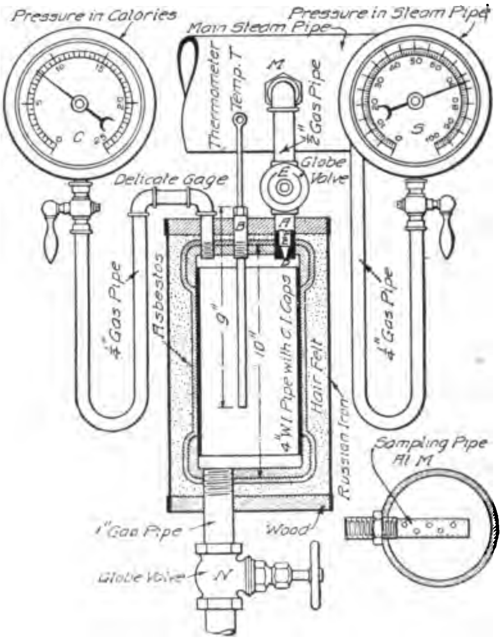


Fig. 42. Diagram of Arrangement of Peabody Throttling Calorimeter

oil; but if mercury is used, the cup must be of iron or steel. A delicate gage *C*, for determining the pressure in the calorimeter, and a pipe and valves at the bottom, complete the apparatus. The valve *N* is sometimes omitted, and a simple pipe used, as the throttling is best accomplished by use of the valve *E* or orifice *D*. All pipes leading to the calorimeter should be well covered with a good nonconductor.

To use the instrument, proceed as follows: Open wide valves *E* and *N*, to bring the apparatus to a uniform temperature; then gradually close *E* until the steam in the calorimeter is superheated; that is, until the temperature as shown by the thermometer is greater than that corresponding to the absolute pressure determined from the reading of the gage *C* and barometric pressure. The result may now be calculated as follows:

x = weight of steam contained in one pound of the mixture from the main steam pipe or other source;

λ_c = total heat corresponding to the absolute pressure determined from the reading of the gage *C* and barometric pressure;*

T = temperature as shown by the thermometer;

t_c = temperature of steam corresponding to the absolute pressure as determined by the reading of the gage *C* and barometric pressure;

q_s = heat of the liquid corresponding to the absolute pressure in the steam pipe;

r_s = heat of evaporation corresponding to the absolute pressure in the steam pipe;

0.48 = heat required to superheat the steam one degree Fahrenheit under constant pressure.

Using the above notations, we find the total heat in one pound superheated steam in calorimeter equals $\lambda_c + 0.48\,(T - t_c)$ B.t.u.; and total heat in one pound moist steam in steam main equals $xr_s + q_s$ B.t.u.

These two quantities are equal; and x being the only unknown quantity, the following equation can easily be solved:

$$x = \frac{\lambda_c + 0.48\,(T - t_c) - q_s}{r_s}$$

---

*Some steam tables use *H* instead of the Greek letter λ (lambda).

Example. Barometric pressure, 14.78 pounds. Absolute pressure in main steam pipe, 87.78 pounds. Absolute pressure in calorimeter, 23.03 pounds. Temperature (T) = 260° F. Then,

$$\lambda_c = 1158.8 \qquad q_s = 288.9$$
$$t_c = 235.45 \qquad r_s = 895.2$$

$$x = \frac{1158.8 + .48\ (260 - 235.45) - 288.9}{895.2} = 0.984 \text{ lb.}$$

Or, in other words, 98.4 per cent of the mixture is steam; or the moisture equals 1−0.984, or 0.016, or 1.6 per cent.

This form of calorimeter is suitable only for cases where the moisture does not exceed three per cent of the mixture. Its principle is based upon the assumption that there is no loss of heat, in which case steam mixed with a small amount of water is superheated when the pressure is reduced by throttling.

BOILER TRIALS

METHOD OF MAKING TEST

Quantities to be Determined. The object of a boiler trial is to determine the quantity and quality of steam the boiler will supply under given conditions, the horsepower of the boiler, the amount of fuel it takes to make the required steam, and the efficiency of operation.

The quantity of steam is taken as the amount of water evaporated, which, of course, is the total amount fed into the boiler during the test, the water level being the same at the beginning and the end less the moisture in the steam.

The quality of the steam can be determined by some form of calorimeter already described; and the efficiency is the ratio of the heat units absorbed by the boiler to the total heat generated in the furnace. The heat utilized in evaporation can be found by multiplying the number of pounds of feed water by the number of heat units required to change the water at the temperature of the feed into steam at gage pressure, making allowance for the moisture in the steam. The heat units supplied can be determined by carefully weighing the fuel used during the test, and deducting the amount of ash and unburned fuel going through the grates, with proper allowance for moisture, multiplying the result by the total heat of combustion of the fuel. The heat of combustion can be obtained by calculation, or by means of a fuel calorimeter.

Conditions Before the Test. Before a test starts, the boiler must be in good working order and fired for some hours before the beginning of the test, so that the brickwork and chimney may be thoroughly heated. Shortly before the test is begun, the fire may be allowed to burn low; and, by reducing the amount of steam taken from the boiler, the pressure can be kept constant. The fire may then be drawn, the grate cleaned, and a new fire quickly started, with wood and fresh coal. Toward the end of the test the fire may be allowed to burn low, and at the close may be drawn and quenched with water, the unburned fuel being allowed for. This method has been supplanted by the "flying" start and stop method, in which beginning and ending conditions are made as nearly alike as possible.

Quantities Which Must be Known. During the boiler trial, observations of temperatures and pressures should be made at the same time, and at about 15-minute intervals. In order to obtain the result of the test, the following must be known:

(1) Amount (in pounds) of coal burned, and number of pounds of ashes left;

(2) Number of pounds of water pumped into boiler;

(3) Temperature of feed water when it enters boiler;

(4) Pressure of steam in boiler;

(5) Quality of steam discharged from boiler—that is, the per cent of moisture in the steam.

(6) The heat value of the fuel.

Weight of Coal. The coal for the furnace can be conveniently weighed in barrels, and may be fired directly from these barrels or dumped on the fireroom floor. The barrels should be carefully weighed when full and empty, and the time recorded, so that there may be no possibility of counting one barrel twice or omitting any. The rate of combustion will be fairly uniform, and the calculations at the times of emptying the barrel will fairly indicate whether or not an error has been made. Any unburned coal should be weighed and the amount subtracted.

Condition of Fire. The condition of the fire should be the same at the beginning and the end. This condition is estimated by the eye; and unless great care is used, an appreciable error is likely to be made. The clinker and ashes should be carefully collected and weighed, and a sample of the ashes analyzed, to obtain the amount of unburned fuel.

Amount of Water Pumped into Boiler. There are several ways of determining the amount of water pumped into the boiler. The best method is to weigh it in tanks or barrels set upon standard scales. There should be two or more barrels of sufficient size, so that the filling and emptying may not be hurried. They should be set high enough to discharge readily into the tank or hot well from which the feed water is drawn. The valves should be large, and should open quickly, so that the emptying may not be delayed. If barrels are used, they should be numbered, and the weight of each accurately noted, so that there may be no mistake in deducting the weight of a barrel from the total weight of barrel and water. When one barrel is being emptied, the other may be filled. The weigher must use care and intelligence; otherwise he may become confused in his records, as in a boiler of considerable size the barrels fill and empty rapidly. At the beginning of the test, the level of the water in the hot well should be recorded, and at the end of the test should be brought to the same mark. If inconvenient to weigh the water, it may be measured by a meter; but if a meter is used, it should be tested and its error determined under like conditions of temperature and pressure. The feed water should be free from air, as otherwise too large a meter reading will be recorded.

The level in the water glass of the boiler should be carefully noted at the beginning and at end of the test. If possible, the level should be constant throughout the test; and if there is any difference between the beginning and the end, due allowance should be made for it.

Temperature of Feed Water. The temperature of the feed water can be taken best by means of a thermometer in a cup filled with oil screwed into the feed pipe near the check valve. If the temperature is nearly constant, readings at 15-minute intervals will suffice; otherwise readings should be taken more frequently.

Steam Pressure. The steam pressure shown by the gage should be as nearly constant as possible throughout the test, and should be practically the same both at the beginning and at the end. Gage readings should be recorded every 15 minutes, and the fireman should see that the pressure is constant. The gage should be tested, and corrected if necessary.

Barometer Readings. Barometric readings should also be taken, two or three being sufficient for a ten-hour run. These readings, in inches, may be made to indicate pounds pressure by multiplying by .491, this being the weight of one cubic inch of mercury. If the trial is on a vertical boiler which furnishes superheated steam because of the heat being in contact with the tubes above the water level, both the pressure gage and the thermometer should be used, so that the amount of superheating can readily be found by subtracting the temperature due to pressure (obtained from the steam tables) from the temperature readings.

Quality of Steam Used. The quality of steam can be readily determined by a calorimeter. If there is sufficient steam space within the boiler, from 1 to 2 per cent priming will generally result. If the steam space is inadequate, there will be more priming. If more than 2 per cent priming is present, the steam will blow white from the gage cocks when opened; if less than 2 per cent, it will appear blue.

Miscellaneous Observations. The above observations are of the more important class, and *must* be taken. In addition to these, it is well to take samples of the flue gas at intervals and from various places in the furnace or chimney, the object being to determine whether there is a sufficient supply of air admitted, or whether there is too much. The draft of the chimney may be measured by means of a U-tube partly filled with water, or by a draft gage.

ABSTRACT OF A. S. M. E. BOILER TEST CODE

It is well to bear in mind that in making the boiler test the utmost care must be used, both in taking observations and in recording them, and in working up the results of the trial. A committee of the American Society of Mechanical Engineers has recommended a code of rules for boiler trials, and the following constitutes an abstract from a voluminous code of rules prepared by this society. The reader is referred to the latest revised code for more complete information on the subject, though it should be remembered that the principles found therein will agree closely with the methods here given.

Preliminaries. 1. In preparing for and conducting trials of steam boilers, the specific object of the proposed trial should be clearly defined and steadily kept in view.

2. Measure and record the dimensions, position, etc., of grate and heating surfaces, flues, and chimneys; proportion of air space in the grate surface; kind of draft, natural or forced.
3. Put the boiler in good condition. Have heating surface clean inside and out; grate bars and sides of furnace free from clinkers; dust and ashes removed from back connections; leaks in masonry stopped; and all obstructions to draft removed. See that the damper will open to full extent, and that it may be closed when desired. Test for leaks in masonry by firing a little smoky fuel and immediately closing damper. The smoke will escape through the leaks if there be any.
4. Have an understanding with the persons in whose interest the test is to be made as to the character of the coal to be used. In all important tests, a sample of coal should be selected for chemical analysis.
5. Establish the correctness of all apparatus used in the test for weighing and measuring. These are: (1) Scales for weighing coal, ashes, and water. (2) Tanks or water meters for measuring water. Water meters, as a rule, should only be used as a check on other measurements. For accurate work the water should be weighed or measured in a tank. (3) Thermometers and pyrometers for taking temperatures of air, steam, feed water, waste gases, etc. (4) Pressure gages, draft gages, etc.
6. Before beginning a test, the boiler and chimney should be thoroughly heated to their usual working temperature. If the boiler is new, it should be in continuous use at least a week before testing in order to dry the mortar thoroughly and heat the walls.
7. Before beginning a test, the boiler and connections should be free from leaks, and all water connections, including blow and extra feed pipes, should be disconnected or stopped with blank flanges, except the particular pipe through which water is to be fed to the boiler during the trial. In locations where the reliability of the power is so important that an extra feed pipe must be kept in position and, in general, when, for any other reason, water pipes other than the feed pipes cannot be disconnected, such pipes may be drilled so as to leave openings in their lower sides, which should be kept open throughout the test as a means

of detecting leaks or accidental or unauthorized opening of valves. During the test the blow-off pipe should remain exposed.

If an injector is used, it must receive steam directly from the boiler being tested, and not from a steam pipe or from any other boiler.

See that the steam pipe is so arranged that water of condensation cannot run back into the boiler. If the steam pipe has such an inclination that the water of condensation from any portion of the steam-pipe system may run back into the boiler, it must be trapped so as to prevent this water from getting into the boiler without being measured.

8. A test should last at least ten hours of continuous running, and twenty-four hours whenever practicable.
9. The conditions of the boiler and furnace in all respects should be, as nearly as possible, the same at the end as at the beginning of the test. The steam pressure should be the same, the water level the same, the fire upon the grates should be the same in quantity and condition, and the walls, flues, etc., should be of the same temperature.

Method of Starting and Stopping a Test. To secure as near an approximation to exact uniformity as possible in conditions of the fire and in temperatures of the walls and flues, the following methods of starting and stopping a test should be adopted.

10. *Standard Method.* Steam being raised to the working pressure, remove rapidly all the fire from the grate, close the damper, clean the ash pit, and as quickly as possible start a new fire with weighed wood and coal, noting the time of starting the test and the height of the water level while the water is in a quiescent state, just before lighting the fire.

At the end of the test, remove the whole fire, clean the grates and ash pit, and note the water level when the water is in a quiescent state; record the time of hauling the fire as the end of the test. The water level should be as nearly as possible the same as at the beginning of the test. If it is not the same, a correction should be made by computation, and not by operating pump after test is completed. It will generally be necessary for a time to regulate the discharge of steam from the boiler tested by means of the stop valve, while fires are being hauled at the beginning and at the end of the test, in order to keep the steam pressure in the boiler at those times up to the average during the test.

11. *Alternate Method.* Instead of the Standard method above described, the following may be employed where local conditions render it necessary.

At the regular time for slicing and cleaning fires, have them burned rather low, as is usual before cleaning, and then thoroughly cleaned; note the amount of coal left on the grate as nearly as it can be estimated; note the pressure of steam and the height of the water level—which should be at the medium height to be carried throughout the test—at the same time; and note this time as the time of starting the test. Fresh coal, which has been weighed, should now be fired. The ash pits should be thoroughly cleaned at once after starting. Before the end of the test the fires should be burned low, just as before the start, and the fires cleaned in such a manner as to leave the same amount of fire, and in the same condition, on the grates as at the start. The water level and steam pressure should be brought to the same point as at the start, and the time of the ending of the test should be noted just before fresh coal is fired.

Keep Conditions Uniform. 12. The boiler should be run continuously, without stopping for mealtimes or for rise or fall of pressure of steam due to change of demand for steam. The draft, being adjusted to the rate of evaporation or combustion desired before the test is begun, should be kept uniform during the test by means of the damper.

If the boiler is not connected to the same steam pipe with other boilers, an extra outlet for steam with valve in same should be provided, so that in case the pressure should rise to that at which the safety valve is set, it may be reduced to the desired point by opening the extra outlet without checking the fires.

If the boiler is connected to a main steam pipe with other boilers, the safety valve on the boiler being tested should be set a few pounds higher than those of the other boilers, so that in case of a rise in pressure the other boilers may blow off and the pressure be reduced by closing their dampers, allowing the damper of the boiler being tested to remain open, and firing as usual.

All conditions, such as force of draft, pressure of steam, and height of water, should be kept as nearly uniform as possible. The time of cleaning the fires will depend upon the character of the fuel, the rapidity of combustion, and the kind of grates. When very good coal is used, and the combustion is not too rapid, a ten-hour test may be run without any cleaning of the grates other than just before the beginning and just before the end of the test. But in case the grates have to be cleaned during the test, the intervals between one cleaning and another should be uniform.

Keeping the Records. 13. The coal should be weighed and delivered to the fireman in equal portions, each sufficient for about one hour's run, and a fresh portion should not be delivered until the previous one has all been fired. The time required to consume each portion should be noted, the time being recorded at the instant of firing the first of each new portion. It is desirable that at the same time the amount of water fed into the boiler be accurately noted and recorded, including the height of the water in the boiler and the average pressure of steam and temperature of feed during the time. By thus recording the amount of water evaporated by successive portions of coal, the record of the test may be divided into several divisions, if desired, at the end of the test, to discover the degree of uniformity of combustion, evaporation, and economy at different stages of the test.

Priming Tests. 14. In all tests in which accuracy of results is important, calorimeter tests should be made of the percentage of moisture in the steam, or of the degree of superheating. At least ten such tests should be made during the trial of the boiler, or as many as may be needed to reduce the probable average error to less than one per cent. The final records of the boiler test should be corrected according to the average results of the calorimeter tests.

On account of the difficulty of securing accuracy in these tests, the greatest care should be taken in the measurements of weights and temperatures. The thermometers should be accurate within a tenth of a degree; and the scales on which the water is weighed, to within one-hundredth of a pound.

Selecting Coal for Analysis. 15. As each fresh portion of coal is taken from the coal pocket, a representative shovelful should be selected from it and placed in a barrel or box, to be kept until the end of the trial, for analysis. The samples should then be thoroughly mixed and broken. This sample should be put in a pile and carefully quartered. One quarter may then be put in another pile, and the process repeated until five or six pounds remain. One portion of this sample is to be used for the determination of the moisture and heating value, the other, for chemical analysis.

Miscellaneous Conditions. 16. The ashes should be weighed dry, and a sample frequently taken to show the amount of combustible material passing through the grate. To get a representative ash sample, the ash pile should be quartered as required for the coal.

17. The quality of the fuel should be determined by analysis.

18. The analysis of the flue gases is an especially valuable method of determining the relative value of different methods of firing or of different kinds of furnaces. Great care should be taken to procure average samples, since the combustion of the gases may vary at different points in the flue; and as the combustion of flue gas is liable to vary from minute to minute, the sample of gas should be drawn through a considerable period of time.

19. It is desirable to have a uniform system of determining and recording the quantity of smoke produced. This is usually expressed in percentages, depending upon the judgment of the observer.

20. In tests for the purpose of scientific research in which the determination of all variables is desirable, certain observations should be made which in general are not necessary—such as the measurement of air supply, the determination of its moisture, the determination of the heat loss by radiation, the infiltration of air through the setting, etc.—but as these determinations are rarely undertaken, no definite instructions are here given.

21. The following two methods of defining and calculating the efficiency of the boiler are recommended:

$$(1)\quad \text{Efficiency of boiler} = \frac{\text{Heat absorbed per lb. of combustible}}{\text{Calorific value of 1 lb. of combustible}}$$

$$(2)\quad \text{Efficiency of boiler and grate} = \frac{\text{Heat absorbed per lb. of coal}}{\text{Calorific value of 1 lb. of coal}}$$

The first of these is the one usually adopted.

22. An approximate statement of the distribution of the heating value of the coal among the several items of heat utilized may be included in the report of a test when analyses of the fuel and chimney gases have been made.

Record of the Test. 23. The data and results of the trial should be recorded in a systematic manner, according either to Table I (see Vol. XXI, Transactions of the American Society of Mechanical Engineers), or according to the following tabular matter (Table II), taken from those "Transactions".

Data and Results of Evaporative Test

Arranged in accordance with the short form advised by the Boiler Test Committee of the American Society of Mechanical Engineers, Code of 1899:

Made by..........................on..............boiler, at..............
To determine..
Kind of fuel..
Kind of furnace...
Method of starting and stopping the test (*Standard* or *Alternate*, Arts. X and XI, Code)
Grate surface..sq. ft.
Water-heating surface......................................sq. ft.
Superheating surface.......................................sq. ft.

Total Quantities

1. Date of trial..
2. Duration of trial......................................hours
3. Weight of coal as fired................................lb.
4. Percentage of moisture in coal.........................per cent
5. Total weight of dry coal consumed......................lb.
6. Total ash and refuse...................................lb.
7. Percentage of ash and refuse in dry coal...............per cent
8. Total weight of water fed to boiler....................lb.
9. Water actually evaporated, corrected for moisture or superheat in steam..............................lb.
10. Equivalent water evaporated into dry steam from and at 212° F...lb.

Hourly Quantities

11. Dry coal consumed per hour.......................lb.
12. Dry coal per square foot of grate surface per hour....lb.
13. Water evaporated per hour corrected for quality of steam...lb.
14. Equivalent evaporation per hour from and at 212° F..lb.
15. Equivalent evaporation per hour from and at 212° F. per square foot of water-heating surface..........lb.

Average Pressures, Temperatures, Etc.

16. Steam pressure by gage..........................lb. per sq. in.
17. Temperature of feed water entering boiler...........degrees
18. Temperature of escaping gases from boiler...........degrees
19. Force of draft between damper and boiler...........in. of water
20. Percentage of moisture in steam, or number of degrees superheating..................................per cent or degree

Horsepower

21. Horsepower developed (item 14÷34½)..................h.p.
22. Builder's rated horsepower.............................h.p.
23. Percentage of builder's rated horsepower developed........per cent

Economic Results

24. Water apparently evaporated under actual conditions per pound of coal as fired (item 8÷item 3)..................lb.
25. Equivalent evaporation from and at 212° F. per pound of coal as fired (item 10÷item 3)..............................lb.
26. Equivalent evaporation from and at 212° F. per pound of dry coal (item 10÷item 5)................................lb.
27. Equivalent evaporation from and at 212° F. per pound of combustible [item 10÷(item 5−item 6)]...................lb.

If items 25, 26, and 27 are not corrected for quality of steam, the fact should be stated.

Efficiency

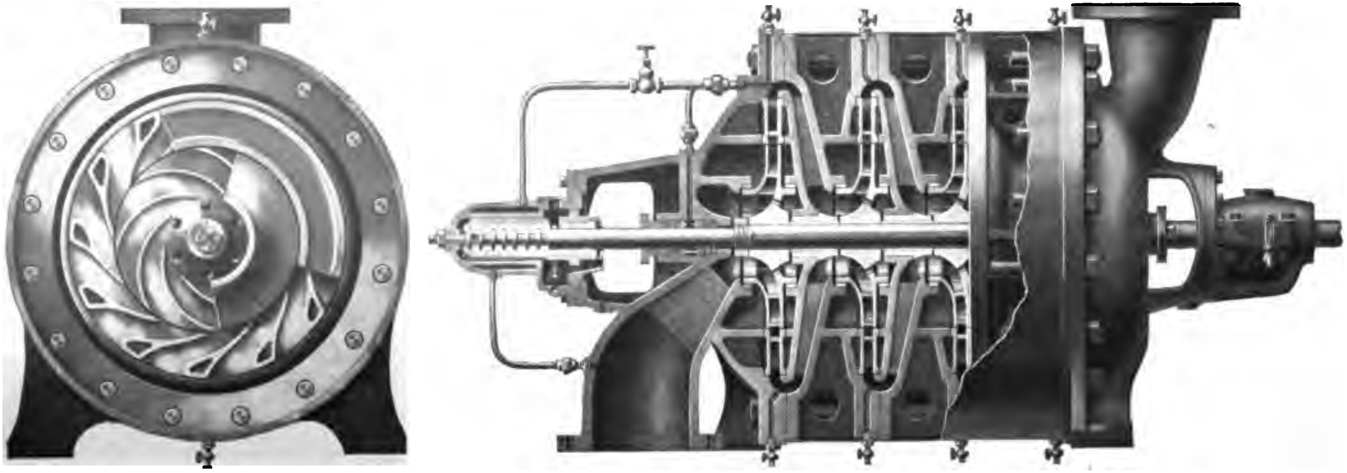
28. Calorific value of the dry coal per pound..................B.t.u.
29. Calorific value of the combustible per pound..............B.t.u.
30. Efficiency of boiler (based on combustible).................per cent
31. Efficiency of boiler, including grate (based on dry coal)......per cent

Cost of Evaporation

32. Cost of coal per ton of —— lb. delivered in boiler room.....$
33. Cost of coal required for evaporating 1,000 lb. of water from and at 212° F.......................................

A log of the test should be kept on properly prepared blanks containing headings as follows:

	Pressures			Temperatures					Fuel		Feed Water		
Time	Barometer	Steam Gage	Draft Gage	External Air	Boiler Room	Flue	Feed Water	Steam	Time	Pounds	Time	Lb. or cu. ft.	



ALBERGER TYPE "V" TURBINE PUMP

Courtesy of Alberger Pump and Condenser Company, New York City

PUMPS

INTRODUCTION

Principles of Action. A pump, primarily, is a machine designed for lifting liquids, or for conveying them to a distance through pipes, or both. To accomplish these results, the principles of suction, lifting, or forcing or any combination of them may be used; in general practice the first is combined with one of the other two.

Suction, so-called, is really the pressure due to the weight of the atmosphere acting to force the liquid into a space wherein a partial vacuum has been created by removing a part of the matter that filled it. The amount of pressure available in any instance for forcing in the liquid, depends upon the completeness with which the matter has been removed from the space in which suction is acting, and on the weight of the atmosphere at that place. If all matter could be removed from the suction chamber, a perfect vacuum would be created and the full pressure of the atmosphere would be effective; a condition closely approaching this is created in the barrel of a pump when no air is present and the plunger or part of the liquid is withdrawn.

If there be any air present, it will expand and fill the vacant space, its pressure falling as the volume increases; the pressure available to force in the liquid by suction will be the difference between that due to the weight of the atmosphere and the final pressure in the suction chamber. The greater the amount of matter removed from the suction chamber, the less will be the resulting pressure therein and the greater the difference available for moving the liquid.

The other factor, the weight of the atmosphere, varies with its condition and the altitude as shown by the barometer. Table I, compiled from "Kent's Mechanical Engineers' Pocket-Book" and "Nystrom's Mechanics," gives barometer readings, the pressure per square inch, and heights above sea level corresponding to each other; the altitude is at 40° latitude and the temperature, 60° Fahrenheit.

TABLE I

Barometer Readings for Different Air Pressures and Altitudes

Barometric Reading in Inches of Mercury	Atmospheric Pressure in Pounds per Square Inch	Altitude Above Sea Level in Feet	Barometric Reading in Inches of Mercury	Atmospheric Pressure in Pounds per Square Inch	Altitude Above Sea Level in Feet
30	14.72	0	23.50	11.54	6778
29.75	14.60	232	23.00	11.30	7375
29.50	14.47	466	22.50	11.05	7985
29.25	14.35	703	22.00	10.80	8609
29.00	14.23	941	21.50	10.56	9247
28.75	14.11	1181	21.00	10.31	9900
28.50	13.98	1424	20.00	9.81	11254
28.25	13.86	1668	19.00	9.32	12678
28.00	13.74	1915	18.00	8.82	14179
27.50	13.50	2415	17.00	8.33	15766
27.00	13.26	2924	16.00	7.84	17448
26.50	13.02	3443	15.00	7.35	19240
26.00	12.77	3972	14.00	6.86	21155
25.50	12.53	4511	13.00	6.37	23212
25.00	12.27	5061	12.00	5.88	25433
24.50	12.03	5621	11.00	5.39	27848
24.00	11.78	6194			

As the weight of a column of water one foot high and one inch square is 0.433 pound, it follows that the atmospheric pressure—which at sea level is ordinarily 14.72 pounds per square inch—can support a column of water as many feet high as 0.433 is contained in 14.72, or 33.9+ feet. The height of column which can be supported decreases as the altitude increases. At the top of a mountain two miles high where the atmospheric pressure is 9.81 lbs., the height of the column would be 22.7 feet.

This is the height which could be barely supported if the vacuum were perfect. In practice, the height to which water can be lifted is much less, because it is impossible to obtain a perfect vacuum on account of leakage of valves and joints, and the atmospheric pressure must overcome friction in pipes and passages, so that the possible lift is reduced to not over 25 feet at sea level and this only for slow working. It is better to attempt only 20 feet or even less if the pump is to work rapidly. If, however, a high suction lift is imperative, it may be obtained by admitting air with the water in suitable proportions to form a heavy spray so that the weight per cubic foot of the mixture is considerably reduced. In this way a lift of as much as 100 feet may be possible, but, of course, at the expense of the weight of water pumped per stroke, so that either the pump must be run at a higher speed or a larger pump must be used. The air should be admitted to the suction pipe through several small openings a little above the level of the water in the supply reservoir. The suction must be primed each time the pump is started.

Probably the earliest example of a practical steam pump was that built at Raglan Castle by the Marquis of Worcester in 1630. This employed both suction and pressure, two vessels making the flow continuous. Steam was admitted from a boiler through valve B', Fig. 1, to the chamber A', and the pressure forced the water upward through the valve F' and pipe E, the valve C' preventing its return to the reservoir. Meantime the chamber A was shut off from the boiler, and the cold water, condensing the steam, caused a partial vacuum so that water was forced up through valve C and pipe D into the chamber A. When A' was emptied and A filled, the steam valves were reversed and A' became filled while A was being emptied.

In practically all pumps, except those to which the liquid comes under pressure, suction is used for filling the cylinders. The suction lift is, however, usually but a few feet except where deep mines are drained, and in the case of air pumps for condensers in which the suction is always kept at the highest possible value. In order to make the suction action as effective as possible, the valves and supply pipes must be kept with all seatings and joints absolutely tight.

When hot water is being pumped by suction, as in the case of a boiler-feed pump taking its supply from a feed-water heater, the lift will be less the higher the temperature of the water. At 141° F. the water will turn into steam under a suction of 24 inches vacuum, and the pump will become *steam bound.* As a matter of practice, it is found inadvisable to try to pump water by suction at a temperature of over 150° F. For higher temperatures the water must come to the inlet of the pump under a head in order to get full pump capacity.

TABLE II

Lift and Inlet Head of Various Temperatures of Water

Temperature of Water (deg. F.)	Practical Lift (ft. hd.)	Suction		Temperature of Water (deg. F.)	Head Needed on Inlet (ft.)
		Vacuum (in.)	Pressure (lb. sq. in. abs.)		
53	23.2	29	0.49	165	1.6
57	22.4	28	0.98	170	2.7
63	21.6	27	1.47	175	3.8
67	20.8	26	1.96	180	5.0
69	20.0	25	2.45	185	6.0
73	19.2	24	2.94	190	7.0
79	17.6	22	3.92	195	8.0
87	16.0	20	4.90	200	9.2
94	14.4	18	5.88	205	10.3
100	12.8	16	6.86	210	11.5
115	9.6	12	8.82		
129	6.4	8	10.78		
143	3.2	4	12.74		
152	1.6	2	13.72		
156	0.8	1	14.21		

Table II gives data in regard to possible lift and necessary inlet head for various temperatures of water handled, at sea level, with the barometer at 30 inches. For atmospheric pressures, less than 30 inches of mercury, the lifts would be reduced as in Table I.

Pumps for handling water of condensation from steam engines, turbines, steam kettles, or heating systems must always be set so that the hot water will come to the inlet under the head needed for its temperature.

Lifting. The lifting pump, Fig. 2, is simply a bucket *B* working in a vertical barrel *A* and so arranged that the water is caught above the bucket and raised on the upward stroke to the top of the barrel or to a point where an overflow is provided. Usually the bucket is filled on the down stroke by means of a valve *C* in the bottom, and if the lift is for any considerable distance, it is necessary to put a foot valve *E* at the bottom of the inlet pipe to prevent the liquid from sinking in the barrel when the bucket descends. By this means suction also is introduced, since the space above the foot valve is filled from the reservoir by suction during the up stroke.

of the bucket. The pump may then be placed at any distance above the reservoir within the limit already stated, and at any distance horizontally; but it should be remembered that the speed of working and the height of lift must be decreased if the horizontal distance is materially increased, and that it is always better to make the suction pipe as short as possible.

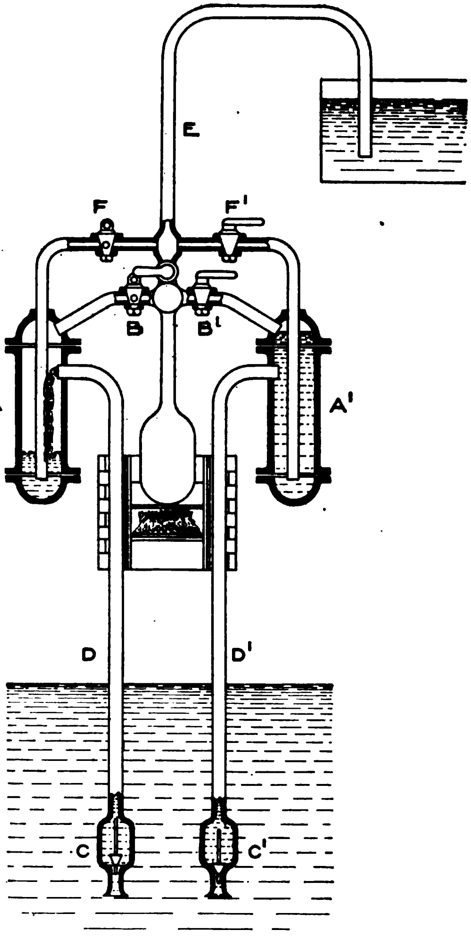


Fig. 1. Early Form of Steam Pump, 1630.

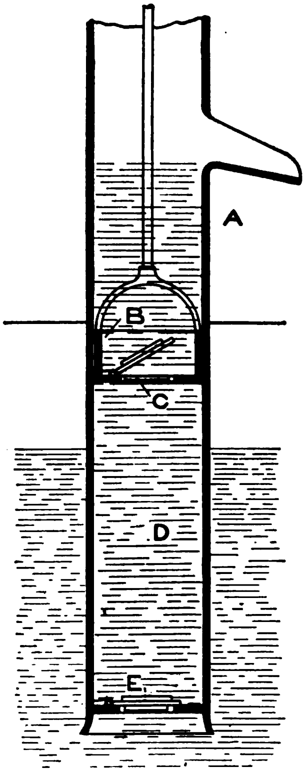


Fig. 2. Lifting Pump.

Forcing. The suction effect is used in all pumps, at least to fill the barrel, but the lifting principle is uncommon except where the discharge is to be directed from a spout at the top or in the side of the barrel, as in mine drainage and house pumps. If it is necessary to raise the liquid to a point above the pump level, either a piston or a plunger working in a closed chamber is used to force the liquid through discharge valves, against whatever pressure may be necessary, into the delivery pipe, and return currents are prevented by the closing of the discharge valves.

A single-acting plunger pump is shown in Fig. 3, the action being the same for a piston or for a double-acting pump except that there are two sets of valves. In the figure, the plunger *P* on the outward stroke draws water from the reservoir through pipe *A* and inlet valve *E* into the barrel *B*. On the inward stroke, the valve *E* will close and, since liquids are practically incompressible, the discharge valve *D* will open allowing the water to pass into the discharge chamber and out through the pipe *C*. Although the force is exerted on the mass of liquid in a direction lengthwise of the barrel, yet, since pressure is transmitted equally in all directions, the valves will open promptly if located in any position with respect to the barrel.

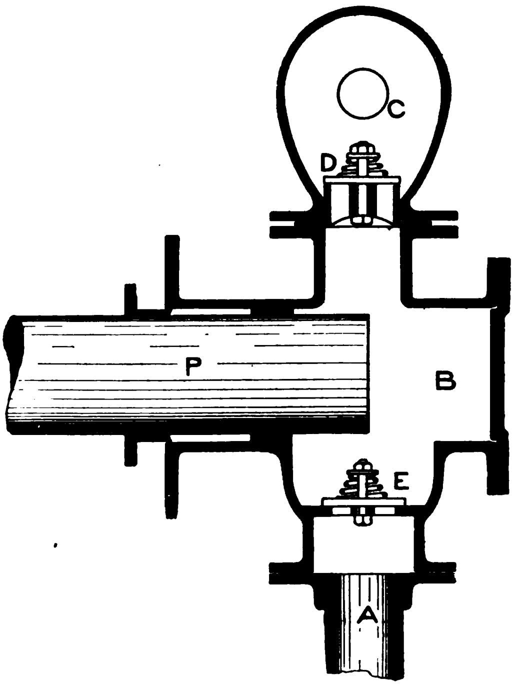


Fig. 3. Single-Acting Plunger Pump.

The pressure against which the pump must act in forcing depends on the weight of the valves, the spring pressure, if any, used to close them quickly, and the height to which the liquid is to be raised, or, as it is technically termed, the *head* against which the pump is to work. For water, the pressure per square inch increases one pound for every 2.32 feet, or, as previously stated, one foot of head produces 0.433 pound pressure per square inch, Table III, There is no theoretical limit to the height to which a liquid may be raised by forcing, but the speed of starting and stopping the column of water, *i. e.*, the number of strokes per minute, must be decreased as the delivery pipe becomes longer, if water-hammer is to be avoided; this is true whether the length be horizontal or vertical. This hammer effect is due to the force necessary to overcome the inertia of the column of liquid and start or stop its motion. If not properly taken into account, either by using slow speeds or providing adequate air chambers to take up the shock, it will always produce destructive results. Wear on the outlet valves also limits the height to which water may be forced, as this wear increases with the head and makes it difficult to keep the valves tight.

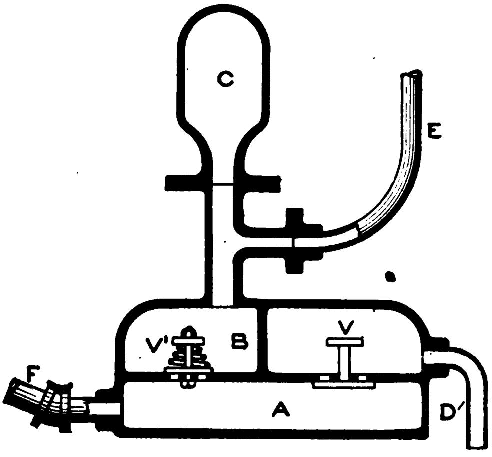


Fig. 4. Hydraulic Ram.

Although no special precautions are required up to pressures of 500 pounds per square inch, care must be exercised from this point up to 2,000 pounds, which is about as high as will be required for lifts or presses. Anything above 2,000 pounds requires the greatest precautions, not only as to strength of parts, form of valves, and packing of joints, but even as to quality of castings, for water will sometimes leak through what appears to be solid metal.

The pressure produced by water-hammer is taken advantage of in one special form of pump, *the hydraulic ram*, Fig. 4, in which the force produced by the inertia of a large column of water suddenly checked is utilized to raise a small column against a high pressure. Water flowing from pipe *F* into the chamber *A* will escape through valve *V* (closed in the figure) to discharge pipe *D;* but, as the velocity of flow increases, valve *V* will be lifted and closed, checking the flow of water. The force thus developed will open valve *V'*

TABLE III

Head, Pressure, and Horsepower at Different Head for Pumping Water

TOTAL PRESSURE		HORSEPOWER FOR 100 GAL. PER MIN.		HORSEPOWER FOR 100 CU. FT. PER MIN.	
Pounds (per sq. in.)	Head (ft.)	Theoretical	Pump Eff. 55%	Theoretical	Pump Eff. 55%
0.43	1.00	0.025	0.046	0.19	0.34
0.86	2.00	0.050	0.092	0.38	0.68
1.00	2.31	0.058	0.106	0.44	0.79
1.30	3.00	0.075	0.138	0.57	1.03
1.73	4.00	0.101	0.183	0.76	1.37
2.00	4.62	0.117	0.212	0.87	1.59
2.16	5.00	0.125	0.228	0.95	1.70
2.59	6.00	0.150	0.275	1.60	2.05
3.00	6.93	0.175	0.318	1.31	2.38
3.03	7.00	0.176	0.322	1.34	2.40
3.46	8.00	0.201	0.367	1.52	2.74
3.89	9.00	0.225	0.413	1.74	3.07
4.00	9.24	0.233	0.424	1.75	3.17
4.33	10.00	0.251	0.460	1.91	3.42
5.00	11.55	9.292	0.530	2.18	3.97
6.00	13.86	0.350	0.636	2.62	4.76
7.00	16.17	0.408	0.742	3.05	5.55
8.00	18.48	0.467	0.848	3.49	6.35
8.66	20.00	0.501	0.920	3.82	6.84
9.00	20.79	0.525	0.955	3.93	7.14
10.00	23.10	0.583	1.061	4.36	7.93
12.99	30.00	0.753	1.380	5.73	10.26
17.32	40.00	1.004	1.840	7.64	13.70
20.00	46.20	1.167	2.121	8.73	15.90
21.65	50.00	1.255	2.300	9.55	17.10
25.99	60.00	1.506	2.760	11.50	20.50
30.00	69.30	1.750	3.180	13.10	23.80
30.32	70.00	1.760	3.220	13.40	23.90
34.65	80.00	2.010	3.680	15.30	27.40
38.98	90.00	2.260	4.140	17.20	30.80
40.00	92.40	2.330	4.240	17.40	31.70
43.31	100.00	2.510	4.600	19.10	34.20
50.00	115.50	2.920	5.300	21.80	39.70
60.00	138.60	3.500	6.360	26.20	47.60
70.00	161.70	4.080	7.420	30.60	55.50
80.00	184.80	4.670	8.490	34.90	63.50
86.60	200.00	5.010	9.200	38.20	68.40
90.00	208.00	5.250	9.550	39.30	71.40
100.00	231.00	5.830	10.610	43.60	79.30
130.00	300.00	7.580	13.790	56.70	103.10
173.00	400.00	10.040	18.400	76.40	136.80
200.00	462.00	11.670	21.200	87.30	158.70
216.50	500.00	12.550	23.000	95.50	171.00
260.00	600.00	15.170	27.600	113.50	206.30
300.00	693.00	17.500	31.800	130.90	238.00
303.20	700.00	17.600	32.200	133.70	239.40
346.50	800.00	20.100	36.800	152.80	273.60
389.80	900.00	22.600	41.400	171.90	307.80
400.00	924.00	23.300	42.400	174.50	317.40
433.00	1000.00	25.100	46.000	191.00	342.00
500.00	1155.00	29.200	53.000	218.20	396.70
600.00	1386.00	35.000	63.600	261.80	476.00
700.00	1617.00	40.800	74.200	305.50	555.40
800.00	1848.00	46.700	84.900	349.00	635.00
866.00	2000.00	50.100	92.000	382.00	684.00
900.00	2079.00	52.500	95.500	393.00	714.00
1000.00	2310.00	58.300	106.100	436.00	793.00

against the pressure of the spring and the head of water in the small pipe *E*, and some water will be forced into chamber *B* and up pipe *E* or into the air chamber *C*, compressing the air. Water will pass into *B* until the force due to water-hammer is so decreased that valve *V′* closes and valve *V* opens once more, when water will again overflow and the process be repeated. The head against which the ram will work may be almost any amount, but the ratio of water raised to that wasted at the overflow will decrease as the head on valve *V′* increases. In any case, the ratio will be small and the ram wasteful, so that its use is advisable only where the supply of water is almost unlimited, other power is difficult to procure, or the amount to be raised is very small. Table IV gives the relation of efficiencies and ratio of lifting to forcing heads, which, according to D. K. Clark, may fairly be expected with a ram of good design.

TABLE IV

Hydraulic Ram Data

Ratio of lift to fall......	4	6	8	10	12	14	16	18	20	22
Efficiency per cent.....	72	61	52	44	37	31	25	19	14	9

The ram should be arranged with a drive pipe whose length is at least five times the fall, in order to give a long column of moving water and increase the water-hammer. The diameter of drive pipe is usually twice that of the lift pipe.

Classification. In classifying pumps, the division may be made according to any one of several methods—as to the details of construction; the principles of action; the means of driving; or the purposes for which they are used.

With regard to the details of construction, which division is, perhaps, the most logical, the classes are as follows: jet; rotary; centrifugal; and reciprocating.

With respect to principles of action pumps may be either lifting; forcing; or these combined with the principle of suction.

With regard to uses, the division is difficult, since the same pump is frequently used in different places for different purposes. Such classes as tank pumps, boiler-feed pumps, air pumps, and mine pumps are fairly definite, but the details vary so much with different makers that it is impossible to draw sharp distinctions. The discussion will be carried out mainly under the classification first given, the description of lifting and forcing pumps, so-called, being placed under *reciprocating pumps.*

JET PUMPS

The jet pump is perhaps best known in the form of the injector, but the principle is worthy of a much wider application than it now has. In the form of a steam or water ejector, the jet pump may be used for lifting water by suction and raising it to a considerable height. A convenient form for an ejector is shown in Fig. 5. The propelling jet may be either steam or water under pressure entering through the valve *A* and flowing from nozzle *D,* which should be made with a decreasing taper like a hose nozzle. If steam is used it will be necessary to provide a small injection pipe with a valve for supplying water to condense the jet and to create a vacuum at the start, otherwise the steam will blow through the apparatus without lifting the water in the suction pipe. When the condensation occurs the heat energy of the steam will be expended in producing a certain velocity in the water thus drawing or forcing it to a considerable height.

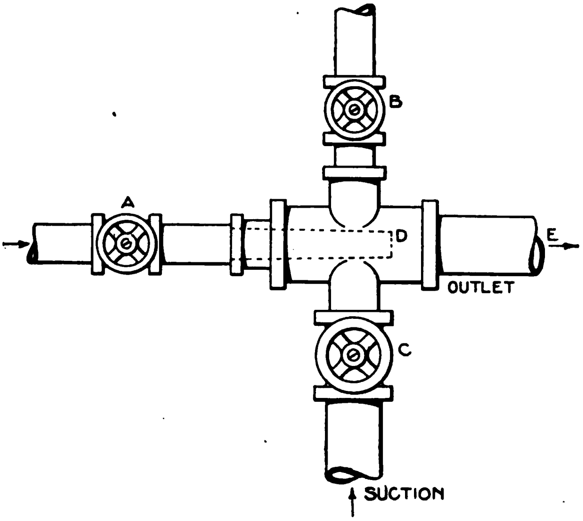


Fig. 5. Jet Pump.

The efficiency of a well-designed steam ejector should be nearly equal to that of an injector and will, like it, depend on the temperature of the water and the height of the suction and lift. In pumping into a boiler, the efficiency of an injector is nearly 100 per cent because almost all the heat energy which is lost in friction goes to heat up the feed water and is, therefore, utilized; but for other purposes, the injector or ejector is wasteful of heat and cannot be considered economical. Its convenience and simplicity, however, are the strong points in its favor, and in places where the amount of water to be lifted is not very large, or if it is to be used where only an occasional demand is made upon it, the jet pump will often be found economical to use rather than one of a more elaborate and costly type.

When water under pressure is used as driving power, it is not necessary to have the inlet at *B*, Fig. 5. The flow of the water from the nozzle will carry along the air and create a vacuum at *D* which will draw the water up the pipe *C*. There is no heat energy available as in the case of steam, so that the water can furnish only such an amount of power as is due to its weight and the velocity with which it leaves the ejector nozzle; and, as the efficiency is low, not over one-fourth of the energy furnished to the ejector at *A* will be available to move water at *E*. For a water injector, it is well to proportion the pipes so that the head on *A times the area of D equals twice the suction and lifting heads combined multiplied by the area of C;* and to make the area of *E* equal to the area of *D* plus the area of *C*, if the apparatus is to be used as a water ejector. For steam at 60 pounds or over, a $\frac{1}{2}$-inch pipe at *A* for a 2-inch at *C* and a $2\frac{1}{2}$-inch at *E* has been found to work well when the head on *E* was small, and if the water is under city pressure a $\frac{3}{8}$-inch pipe at *B*.

It is well to remember that the energy of a jet of either steam or water varies directly as the first power of the weight of the jet, and directly as the square of the velocity of flow. This may be seen from the expression for the available energy per second of any moving mass

$$E = \frac{W v^2}{2 g}$$

where W is the weight flowing per second, v is the velocity in feet per second, and g is the acceleration due to gravity; therefore, for good efficiency, it is best to use high pressure whenever possible.

ROTARY PUMPS

Rotary pumps have been but little used because, as usually designed, their efficiency has been low. They are, however, useful in many cases and are well adapted for moving large volumes of liquid at low pressures, which is done by catching the liquid between the lobes of the revolving propellers and the casing of the pump and sweeping it around from the suction pipe to the discharge pipe, its return being prevented by the lobes and cylinders in the center.

There are many forms of rotary pumps, but as their only difference is in the design of the lobes and the cylinders, two will be sufficient to illustrate the principles. In Fig. 6 is shown the Berrenberg pump; here the lobes are made by two pieces of tubing fastened opposite each other and extending from the semi-cylindrical openings and making a joint with the other lobe by fitting in, as shown. The axles are geared together outside the casing and are supported by bearings inside and outside, which are tapered to allow taking up wear and keeping the shafts true. The curves in Fig. 7 show the results from a series of tests* made on a 2-inch pump by Mr. R. A. Hale. These show that the efficiency of the pump increases up to a certain point with the pressure against which it is working, and then falls off; while a comparison of the curves at different speeds shows that the efficiency becomes less as the speed increases. This is apparent because the loss from friction is not doubled by doubling the head, while the amount of water will be the same per revolution, no matter what the pressure may be. An exception to this is due to slip which increases as the pressure becomes greater. Hence the useful work will increase up to that point where the loss due to leakage and friction more than balances the increase of work due to the increased head. The same reasoning applies to the speed, except that in this case the friction work will increase in proportion to the

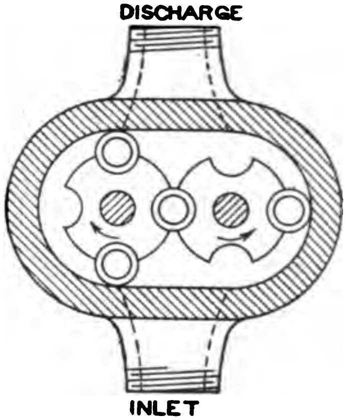


Fig. 6. Berrenberg Rotary Pump.

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*See Barr's *Pumping Machinery*.

speed, so that the gain from the added work due to the increase of speed is not as great as from the increase of head.

Another style of rotary pump, Fig. 8, shows the two pistons so designed that their bounding surfaces are always in contact, thus forming the joint. In this type it is important that the surfaces be of the correct shape, otherwise a pocket will be formed in which water will be caught and this water will be compressed as the volume of the pocket becomes smaller. As water is practically incompressible, it must either leak past the joint or burst the pump. In order to prevent this, a port is sometimes cut in the casing to allow the water to bypass and relieve the pressure. If, however, the outline of the lobes is made of the right shape, there will be no compression and the ports will not be necessary. The cycloid curves should be used for the outline of the lobes as they can form the whole outline and will make a smooth surface which will not create pockets at any part of the revolution. The involute curve has sometimes been used, but it is not good as it does not return on itself, and must, therefore, be cut off by the arc of a circle on the end of the lobe, leaving corners which form compression pockets.

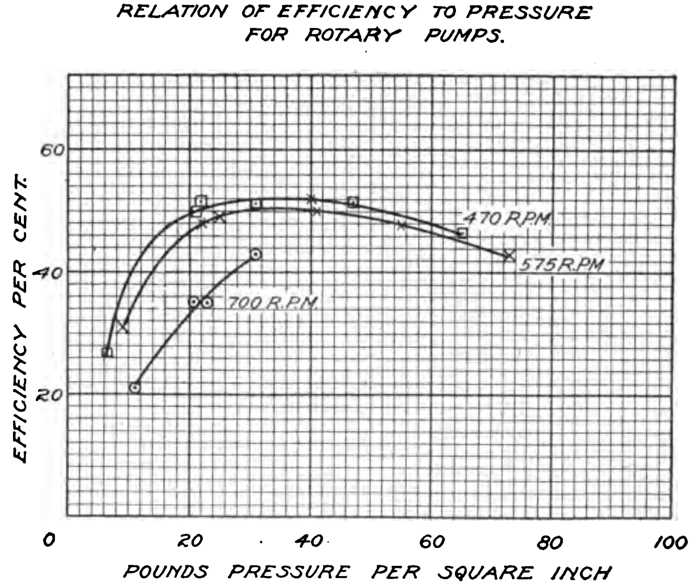

Fig. 7. Tests on a 2-Inch Rotary Pump.

With respect to the effect of the speed on the volume of water pumped, the experiments above noted showed that, within the stated limits, the volume varies nearly as the speed, and that at the same speed, the volume is a little less at high pressure than at low pressure, but does not fall off rapidly as the pressure increases. The data, however, is not complete enough to be conclusive.

The rotary pump is often used for fire purposes; also where portability is of more importance than efficiency; or where first cost is a great consideration. It can be run at high speed, and has a large capacity, for the space occupied, but it is not suitable for large or permanent work except at very low heads.

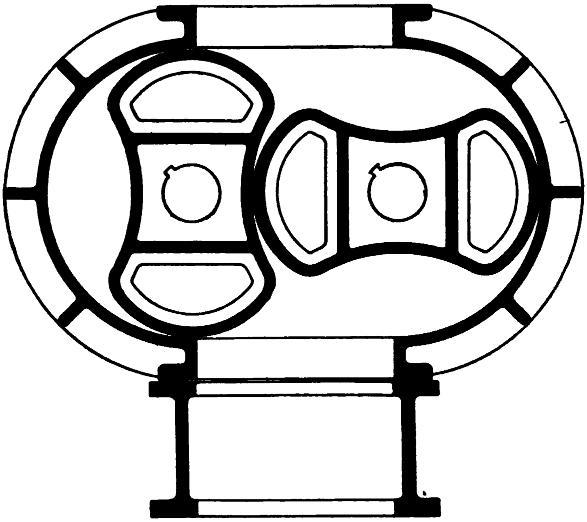

Fig. 8. Double-Piston Rotary Pump.

CENTRIFUGAL PUMPS

Centrifugal pumps operate by the familiar force which throws the mud from the carriage wheel and the water from the lawn sprinkler. A wheel *W*, Fig. 9, with curved blades, revolves in a casing *C* and, when the casing is filled with water, throws it to the outside thus creating a suction at the center and drawing up water through the suction pipes. The velocity and whirling motion given to the water send it to the outside of the casing and out through a delivery pipe *P*, the casing increasing in size up to the outlet to accommodate the increase in the volume of water carried. The blades are given a backward inclination at the wheel center so that water may enter without shock, and the angle which the blades make with the radius is increased towards the outer end so that the water gradually attains some rotary velocity and great radial velocity due to the wedging action as it passes outwards; and on leaving the blades it has reached high speed. If the blades are radial at the outer end, the discharge will be greater for a given speed, but on the other hand there is the disadvantage that the speed cannot be reduced without stopping the action altogether and thereby reducing the efficiency.

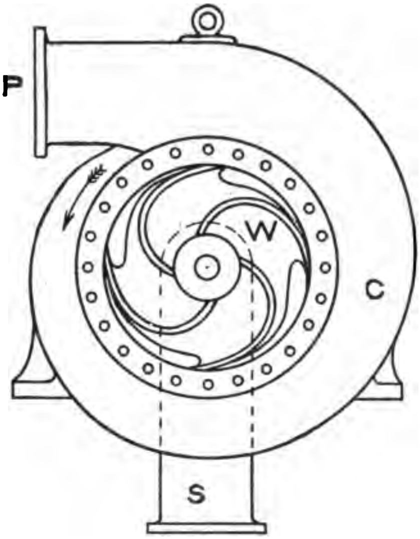

Fig. 9. Centrifugal Pump.

Curve of the Blades an Involute. Rankine states that *the curve of the blade should be an involute of a circle, i. e.*, a curve drawn by a point in a string as it is unrolled from the circle, as shown in Fig. 10. The method of drawing the involute is as follows:

Let *BC* be the inner bounding circle of the blades and *B* the point at which a vane is to start. Draw a tangent to the circle through *B* and through the same point at an angle of 40 degrees with the tangent, draw another straight line *BE*. Draw a concentric circle tangent to *BF*, which is perpendicular to *BE*. If *B* were a point in a string, and this were unrolled from the inner circle, the point *B* would trace an involute *BGH*. For the first form of curve mentioned, this would be continued to the outer bounding circle where it should make an angle of about 15 degrees with the tangent, as *LHM*. For the Rankine blade, the reverse curve *HKA* should be drawn—usually the arc of a circle radial at the point *H*. In order to work without shock, the angle of the blade with the tangent at the inside end *B* should be such that its tangent equals the radial velocity of the water divided by the circumferential velocity of that point on the wheel. It is often made 45 degrees, which is found to be satisfactory for the average case. The angle at the outside should be 15° if there is no diffusing chamber, or if the discharge pipe is not of increasing diameter, in order to gradually lessen the velocity of the water after it leaves the wheel. But this will necessitate a high rotary velocity of the blades, and it is sometimes better to use a diffusing chamber—or an increasing discharge pipe—and make the blades of the Rankine form, running the wheel at a lower speed unless the conditions make it necessary to be able to run at a given medium speed for a partial discharge. The casing should be shaped to give the water a gradually increasing velocity from the time that it enters the suction pipe until it reaches the circumference of the wheel, and then a decreasing velocity until it leaves the discharge pipe. The spiral casing is often recommended because

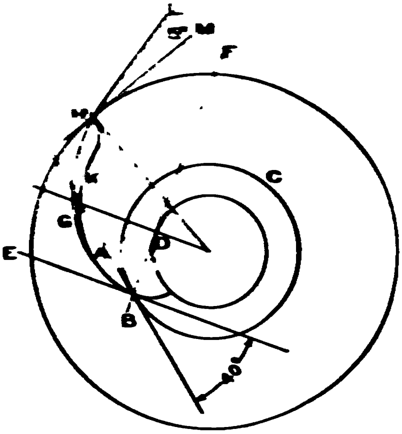

Fig. 10. Involute Diagram.

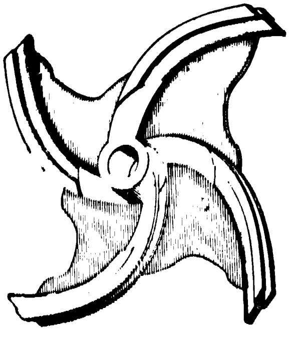

Fig. 11. Blade Used on Small-Sized Centrifugal Pump.

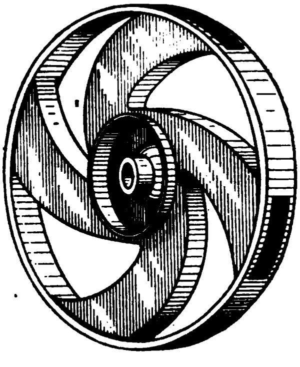

Fig. 12. Hollow Arm Type of Blade.

the centrifugal force given by the rotary motion is radial, not tangential, and the water must be given time to change its direction or it will spend much of its energy in eddies and useless work.

In Fig. 11 is shown a form of blade used for small sizes of pumps and for thick liquids. A hollow-arm type of blade, Fig. 12, which is used in large pumps, has the advantages that the water is thrown outward without any churning motion, and that there are no dead spaces. Fig. 13 shows the type of blade used for dredges with large openings for the passage of sand and mud.

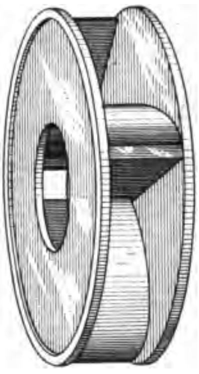
Fig. 13. Type of Blade Used for Dredges

Fig. 14 shows a proper arrangement of the different parts which is satisfactory and also gives an idea of the shape and relative proportions of a standard centrifugal pump.

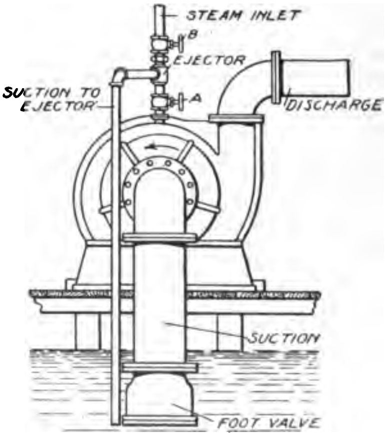

Fig. 14. Standard Arrangement for Centrifugal Pump

Speed. The speed is increased as the height of the lift increases, but not in exact proportion, because the increase of speed for an increase of 10 feet in lift is greater at low than at high heads. Fig. 15 shows the relation between head and speed in two pumps of the same make, the No. 2 having a capacity of 100 gallons per minute at the speeds given and the No. 6, a capacity of 1,200 gallons. The points at which the curves cut the axis of speed show that the No. 2 pump will fail to work at a speed below 250 r.p.m. and the No. 6, below 125 r.p.m. The pump may be set in either a vertical or horizontal position and may have the suction on one side or both—the latter is better as the forces due to lifting the water in the suction pipe are thus balanced and no end thrust is produced. It is necessary to have some means of filling the pump casing with water, *i.e., priming* it, as the suction will not start until the pump is so primed. If water under pressure is not available, it is necessary to install a steam injector or to provide a foot valve which will be tight enough to hold the water in the suction pipe at all times. Makers recommend that, in addition, a flap valve be installed at the top end of the discharge pipe to assist this action.

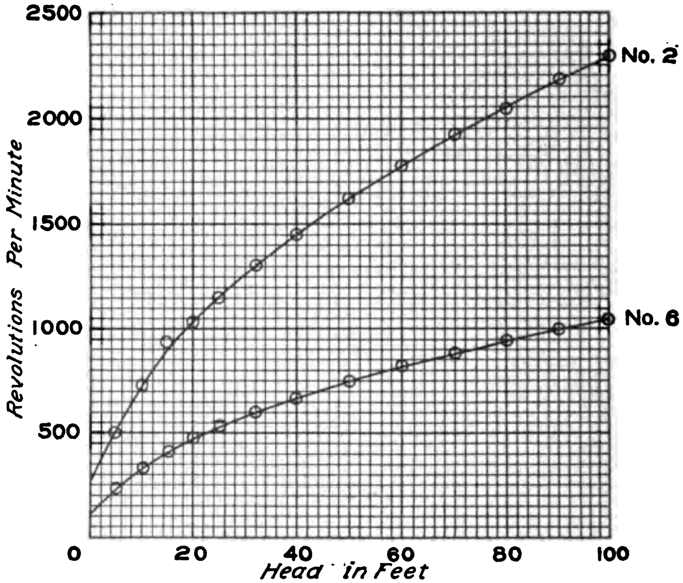

Fig. 15. Graphical Test of 100-Gallon and 1200-Gallon Pumps

Types of Centrifugals. *Whirlpool Type.* According to the method of discharge and shape of the chamber, centrifugal pumps are classified as whirlpool, volute, or turbine. The whirlpool type has a casing shaped so that a ring of water of the same width as the impeller openings surrounds the impeller. Water leaves the impeller in a spiral path with a large tangential component of the velocity. The velocity decreases as the area of the stream increases and at the same time the pressure increases until the water reaches the spiral or circular chamber surrounding the whirlpool, whence it is led to the discharge pipe. In Fig. 16 is shown the section of a whirlpool type and the path of the water.

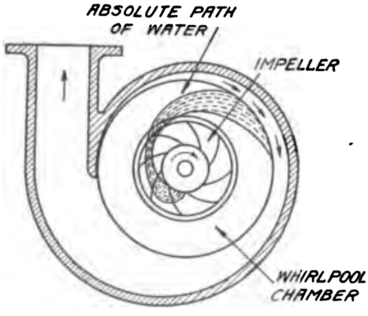

Fig. 16. Whirlpool Type of Pump Casing

Volute Type. Volute pumps, Fig. 17, have no whirlpool chamber, the change from velocity to pressure energy taking place in the casing, which is of volute form and of increasing diameter up to that of the discharge pipe and is designed so that the velocity of flow is equal at all sections around the circumference but decreases from the impeller outlet to the casing outlet. This directs the water more nearly in its natural course than does the whirlpool form, hence it has better efficiency; it also has a larger capacity for a given size of impeller owing to decreased leakage.

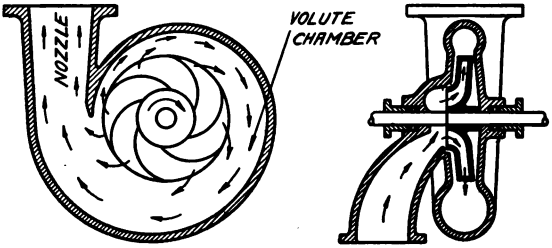

Fig. 17. Sections of Volute Type of Pump—Single Inlet

In Fig. 18 is shown a special form of casing having the suction as well as the discharge chamber of volute form. The section through the shaft center indicates the arrangement and form of the suction and discharge chambers, also the form of the helicoidal impeller which is designed to throw the water into the discharge with a spiral motion.

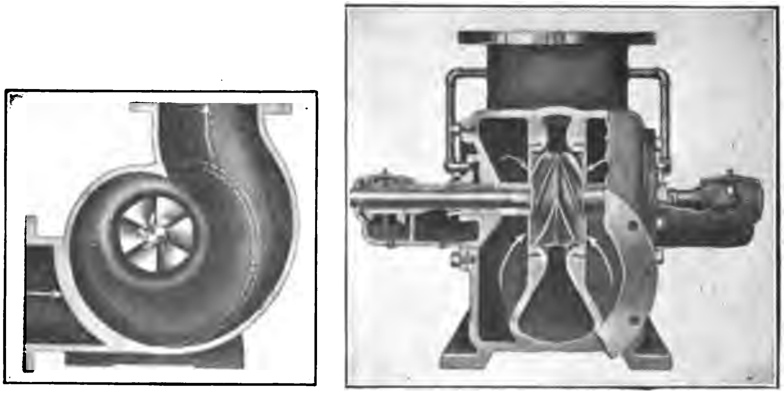

Fig. 18. Special Volute Suction and Discharge Chambers—Double Inlet

Turbine Type. In the turbine pump, diffusion vanes are provided in the whirlpool chamber, as shown in Fig. 19. These direct the water in widening paths, cut down eddies and friction, and give efficient conversion of velocity energy to pressure energy.

Of late years much attention has been paid to adapting the impeller and casing to the service to be performed. The open type, Figs. 11 and 13, is suitable only for low heads and its use limits the field of the centrifugal pump to not over 35 feet for efficient working. Closed vanes, diffusion rings, and labyrinth packings at the hub or circumference of the impeller to prevent leakage from discharge to suction have improved the performance so that heads up to 80 feet are handled with a single stage at good efficiency with the volute type, and heads up to 170 feet with the turbine type. For small sizes, the efficiency will be 30 to 40 per cent; for large sizes, 75 to 85 per cent.

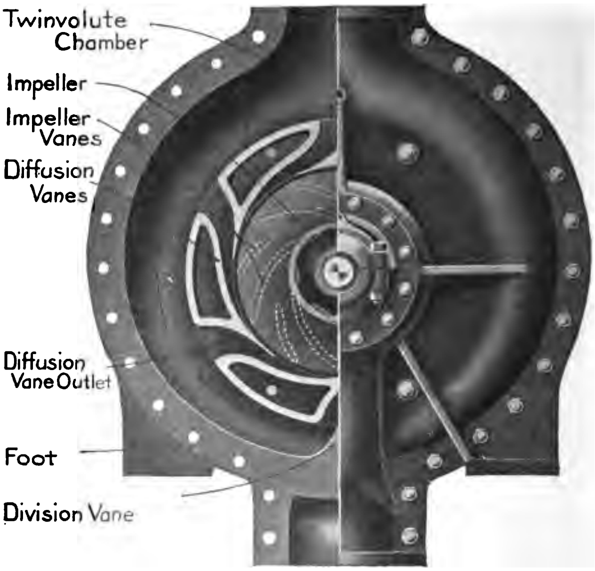

Fig. 19. End Section of Watson-Stillman Single-Stage Twin-Volute Turbine Pump
Courtesy of Twin-Volute Pump Company, New York City

Staging. When greater pressures are desired, two or more propellers are arranged to work in series, the first discharging to the intake of the second, and so on. This staging is carried in some cases to as many as 6 impellers, pumping up to a pressure of 1000 pounds or 2500 feet head. The impellers are usually arranged in a single casing with separate chambers for each stage, as shown in Fig. 20. This involves considerable end thrust, as it is impossible to use double suction and it is necessary to provide thrust collar bearings on the shaft to care for this. In some designs, such as shown in Fig. 21, the impellers are arranged back to back so that the thrust is balanced. Discharge from all stages but the last is usually into a circular return chamber that permits flow from all points on the circumference of the impeller direct to the inlet of the next stage. In Fig. 20 this arrangement is shown clearly.

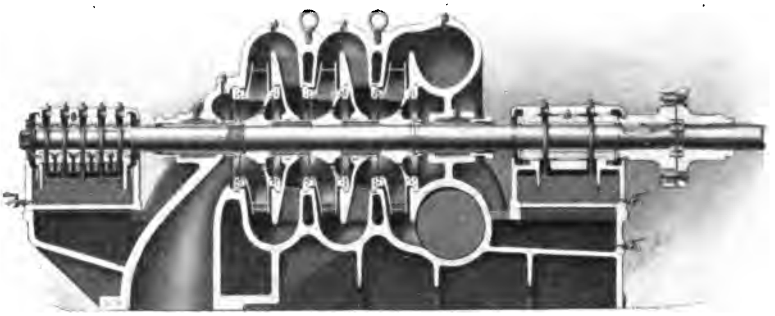

Fig. 20. Typical Section of De Laval Multi-Stage Centrifugal Pump

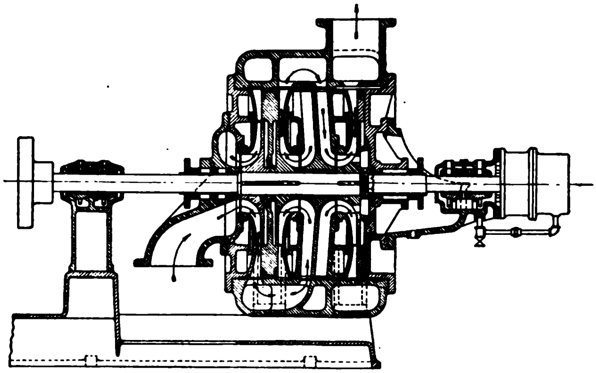

Fig. 21. Three-Stage Pump with First Two Stages Balanced

Characteristics of Centrifugal Pumps. Centrifugal pumps must be carefully designed according to the head against which they are to work, the capacity required, the liquid to be handled, and the range of operating conditions to be met.

The relation of speed to head is shown in Fig. 15, and it will be noted that owing to the difference in shape of the impeller and casing the speed change required for different changes in head is much greater for No. 2 than for No. 6. Change of speed may also be used to vary the capacity as indicated in Fig. 22. Theoretically, the head against which a pump will act varies as the square of the speed, the capacity directly as the speed, and the horse-power required to drive it as the cube of the speed. Actually the effects of friction and the shape of the impeller and the casing cause considerable departure from the theoretical laws, especially as to the horse-power when the speed is constant and the head and capacity vary interdependently. In Fig. 23 are shown the actions of a pump run under varying conditions of head and speed and also the resulting capacity and efficiency. Efficiency increases as the speed (and hence the head) increases up to the point where disk friction increases faster than water horse-power; then the efficiency falls off more or less slowly.

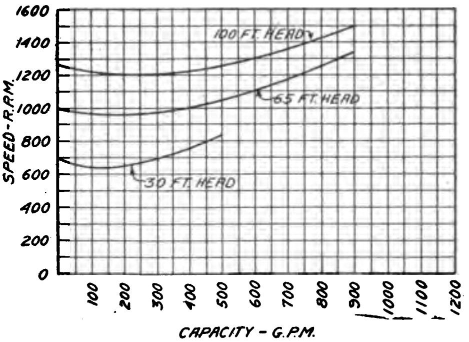

Fig. 22. Variation of Capacity with Speed for Centrifugal Pump

Centrifugal pumps are largely used for boiler feeding, protection systems, deep-well and mine pumping, drainage and irrigation works, condenser auxiliaries, and, recently, for large water works.

Operation. When starting up a centrifugal pump, the discharge valve should be closed. This assists in priming the pump and, with some types of drive, prevents an excessive starting load on the engine or motor. After the pump is primed and up to speed, the valve is slowly opened until the desired capacity is obtained. The speed may be altered by control of the driver until the head and capacity are as desired. Beyond that, the attention needed is to see that the bearings are properly lubricated and that water is circulating properly in the thrust bearing, in case one is used.

Stuffing-boxes should be watched to see that they do not leak, and in case of a multi-stage pump the casing should be opened occasionally to check the register of the impellers with the discharge openings.

To shut down the pump, close the discharge valve slowly so as to reduce the load on the driving motor and prevent any surge on the pipe line when the motor is stopped. Then shut down the motor or engine, and if the pump is exposed to freezing weather, drain it so that ice will not form in the impeller, casing, or valves.

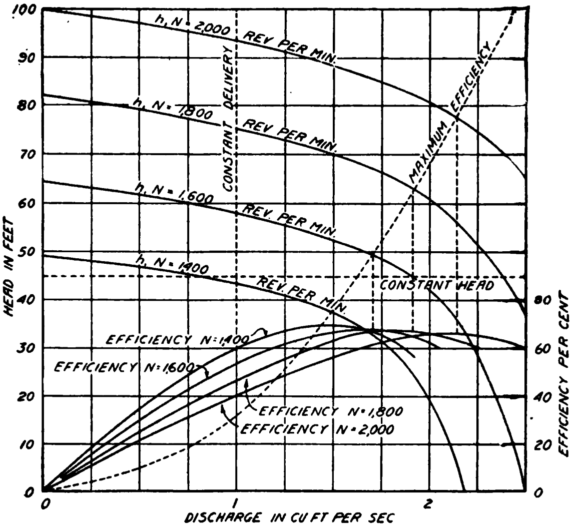

Fig. 23. Discharge Rate and Efficiency of Centrifugal Pumps for Various Speeds

RECIPROCATING PUMPS

Lifting Pumps. The only pumps which work entirely by lifting are the old-fashioned chain devices in which a series of disks mounted on a chain are drawn up by a sprocket wheel through a tube, bringing the water with them. In this form the motion is always in one direction and the action is a purely lifting one; on the other hand, it is common to include in this classification those pumps which fill by the action of suction and deliver their stream by lifting, Fig. 2. These pumps are used largely in mines and for domestic purposes. They have the disadvantage that the pump bucket must not be over 20 feet above the water and the rest of the lift must be made by the rise of the bucket, necessitating either a long rod, or pumping in relay.

Such pumps were used in the Cornish mines in the time of Watt when the engines were placed at ground level, and the rods made of a length sufficient to reach to within 20 feet of the bottom of the shaft. In some cases these pump rods were as much as 480 feet long, and the design of the great pieces was a difficult problem. The walking-beam engine was used largely to drive the pumps, and the whole machine was a huge and wasteful affair.

At the present time, the long pump rod is used to some extent, but it is driven by a vertical cylinder set over the top of the mine shaft.

The *size of the pump cylinder* depends upon the volume of water to be raised and the speed of the pump. When heavy masses are to be moved, as is the case when long rods are used, the speed must, of course, be slow. For the great engines of Watt's time it was about 15 strokes per minute, while in modern pumps it is 25 to 35 strokes per minute. The cylinder must be made of such size that at this speed it will lift the required amount of water.

For example, if it is desired to raise 100 gallons per minute, and the pump is to run at 30 strokes, the volume to be raised is $100 \times 231 = 23{,}100$ cubic inches, and the volume per stroke is $23{,}100 \div 30 = 770$ cubic inches approximately. A usual value for the stroke of pumps of this size is 16 inches, which, if there were no allowance for leakage, would make the area of the cylinder $770 \div 16 = 48.13$ square inches. The allowance for leakage or slip should be, for a pump of this size and speed, about 3 per cent—this would, of course, increase with increase in speed and decrease with increase in size. Allowing 3 per cent slip, the area should be $48.13 \times 1.03 = 49.58$ square inches which is that for a circle of about $7\frac{15}{16}$ inches diameter, so that 8 inches would be used and the area would then be 50.26 square inches.

To find the force needed to lift this bucket, it is necessary to know the height to which the water is to be raised. Suppose this to be 200 feet; then the pressure per square inch will be $200 \times .433 = 86.60$ pounds and the force needed, $86.60 \times 50.26 = 4{,}352 +$ pounds. To this must be added the weight of the bucket and rod, as both must be lifted at each stroke by the driving head at the top of the shaft. The rods are usually made of wood with the sections fastened together by iron couplings. The proper size for the above pump is 4 inches diameter, which, for a rod 200 feet long, would weigh, at 45 pounds per cubic foot, $45 \times \frac{\pi \times 4^2}{4 \times 144} \times 200 = 785$ pounds (about), and the bucket and fastenings will easily make this 1,000 pounds; the whole weight to be lifted will then be 5,352 pounds, which, at 30 strokes per minute, will call for the expenditure of

$$\frac{5{,}352 \times 30}{33{,}000} \times \frac{16}{12} = 6.5 \text{ H. P. (nearly)}$$

This is the power necessary to run the pump aside from the friction of the machinery.

Although, at the present, high lifts are largely made by using a forcing pump at the bottom of the shaft, this was not known at the time of the introduction of the pumping engine in the Cornish mines, and when it was necessary to raise water from a depth greater than could well be handled in one lift, it was accomplished by using pumps in relays. One engine was installed at a depth of some 240 feet from the bottom of the mine, with its pump cylinder within 20 feet of the bottom, and raised the water into a reservoir from which it was taken by another pump, and so on. Instances are recorded in which pumps having pistons 24 inches in diameter and a stroke of 10 feet, raised 4,614,800 gallons per 24 hours.

Forcing Pumps. For raising water to a height greater than can be conveniently overcome by lifting, or when the discharge is desired at a distance from the pump, it is better to use the forcing type, Fig. 3. There are, however, many modifications in common use. For example, if the lift to the pump be great, it is common practice to install a foot valve at the bottom of the suction pipe, as well as to use admission valves to the pump chamber. The arrangement will keep the suction pipe filled at all times and will overcome the tendency of the water to drop out of the pump chamber while the suction valve is closing.

The most common form of forcing pump is the double-acting piston type, Fig. 24. As the piston P moves to the right, it will create a suction in the left-hand end of the cylinder, drawing in water through the valves AA and the suction pipe S. At the same time pressure will be exerted in the right-hand end of the cylinder and water will be forced out of valves D_1D_1, into the discharge chamber and up the pipe K. On the reverse stroke, water will be drawn in at valves A_1A_1 and be forced out of DD.

As in the case of lifting pumps, the volume to be raised and the speed at which the pump can be run, determine the size of the piston; however the speed in the forcing pump is usually greater than in the lifting type. The pump must not be placed over 20 feet above the level of the water which it is to raise, hence for a high head the greater part of the lift must be obtained by forcing against the head above the pump. It is a common rule that *the travel of a pump piston should not exceed 100 feet per minute*, and, taking the same problem as for the lifting pump, this gives, $\frac{23,100}{100 \times 12} = 19.25$ square inches as the area of the piston. At the increased speed, the slip will be greater, hence it will be necessary to allow 5 per cent, or an area of $19.25 \times 1.05 = 20.21$ square inches corresponding to a diameter of $5\frac{1}{16}$ inches.

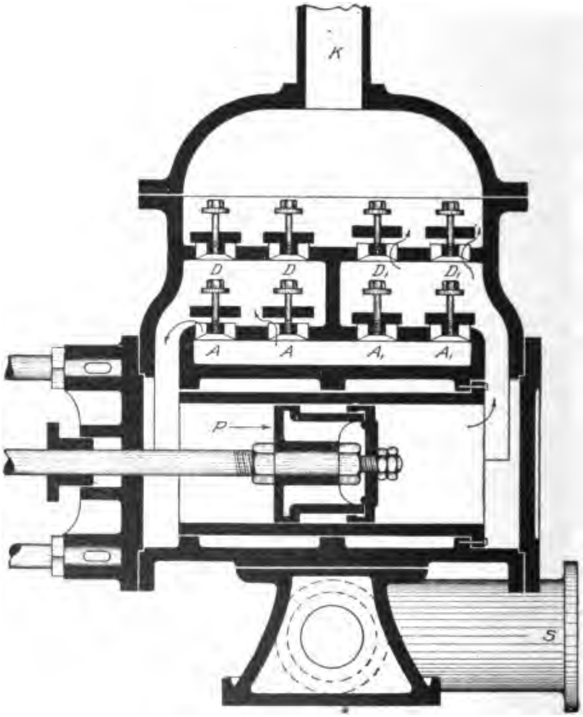

Fig. 24. Double-Acting Forcing Pump.

The head would be the same, hence the total pressure per square inch would be the same as for the lifting pump, but the power would be increased. The total force on the piston will be 20.21 × 86.60 = 1,750.1 pounds. At 100 feet per minute this will require $\frac{1{,}750.1 \times 100}{33{,}000}$ = 5.30 H. P., which is less than before because the weight of the pump rod is not lifted at each stroke. If the rod be counterbalanced by a weight at the opposite end of a walking beam, the lifting pump will have a slight advantage owing to the smaller slip.

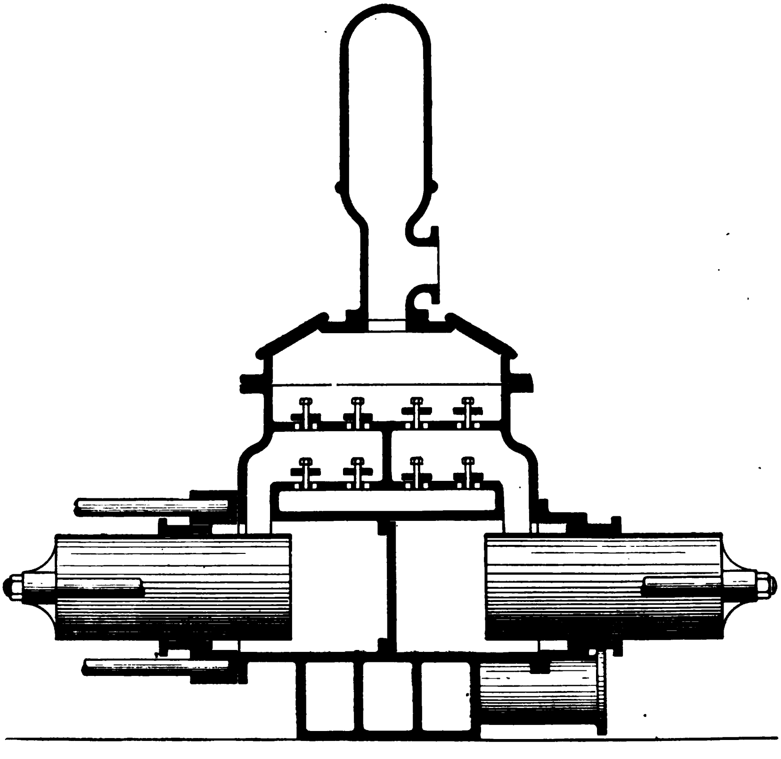

Fig. 25. Double-Acting Double Plunger Pump.

The pump shown in Fig. 24 is double-acting, *i. e.*, it works on both strokes, but pumps, especially of the vertical type, are often made single-acting to suck on the up stroke and to force on the down stroke; these having only half the capacity of the double-acting for the same size of cylinder.

The great difficulty with the piston is in keeping the packing tight or of knowing when it leaks; the repacking of the piston is a difficult operation as the pump must be dismantled in order to get at it. For this reason the plunger pump is often preferred and is used either single-acting with stuffing box around the plunger, Fig. 3; double-acting with two plungers, Fig. 25; or double-acting with one plunger, Fig. 26. The advantage of the last named over the piston type is, that for high pressures it is more easily kept tight, and for gritty liquids the wear is taken by the bushing which is more easily and cheaply replaced than a lining to the cylinder. The piston pump is more compact; but as the plunger type does not require a bored cylinder, the first cost is not materially different.

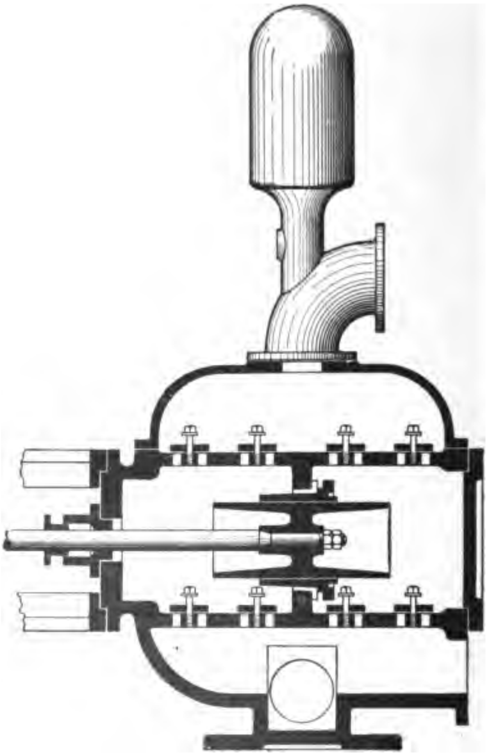

Fig. 26. Double-Acting Single-Plunger Pump.

The two-plunger pump with outside yoke is still larger than the single-plunger double-acting type but it can be easily repacked, can be kept tight against high pressures, and any leaking is instantly detected; for these reasons, it is a favorite. The double-acting pump not only has greater capacity, as above mentioned, but, on account of its continuous action, produces a much steadier flow than the single-acting type.

A modified form of Worcester's Engine, which was shown in Fig. 1, is seen in the pulsometer or hydrotrophe, Fig. 27, a type which is still used to a considerable extent where extreme simplicity is desired. The ball *B* rolls so as to close first *A′* and then *A;* with the ball in the position shown and the chamber *D* filled with steam, water will be drawn up through *F* by the vacuum caused by condensation of the steam. Meantime steam will enter *D′* through *A* and force the water out through the check valve *G*. This will continue until the steam in *D* is all condensed, when the rush of the water, due to its inertia, will drive the ball valve *B* over against port *A*, thus reversing the action. It is entirely automatic and, as the machine is the acme of simplicity and may readily be made with large openings, it will handle dirty liquids with a minimum of attention. Its usual heat efficiency is 1.2 to 1.5 per cent, but this is not as objectionable as it seems, since small reciprocating steam pumps seldom do any better. *C* is a suction air chamber connected with the opening *E* to equalize the flow of water.

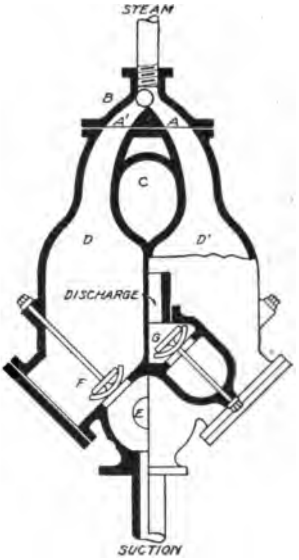

Fig. 27. Pulsometer.

VALVES

Pump valves must be made so that they will open and close quickly, completely, and with little friction; furthermore the design must be such that the valves shall offer no obstruction to the passage of the water, and yet shall allow little leakage of water past the valves after the reversal of motion of the piston and before the valves have seated. Quick opening requires a light valve with slight motion, but quick closing demands either a heavy valve or a spring to hasten its action. In older pumps it was the custom to use one large valve with a lift sufficient to give the required passage; the valve was then heavy enough to close of its own weight, but was clumsy and hard to fit to a seating. In modern practice the required area is divided among several small valves so that each one is easily and cheaply renewed in case of accident or wear, and quick closing is obtained by the use of springs on the spindles of the valves.

Valves are classified, according to the motion, as flexible, hinged, poppet, and ball; and according to the seating, as cushioned and ground.

Flexible Valves. The flexible valve is the oldest type, and is, in some ways, the simplest. It is generally made of rubber, as this material gives the greatest flexibility with the best seating. The valve is made as a solid disk—the opening being obtained by the flexibility of the valve itself—and is usually of the style shown in Fig. 28. The seat is made with radial grids to take the pressure of the water, the openings between the bars being made equal to the thickness of the disk; this thickness depends in turn on the diameter of the disk, and is often made according to the dimensions given in Table V.

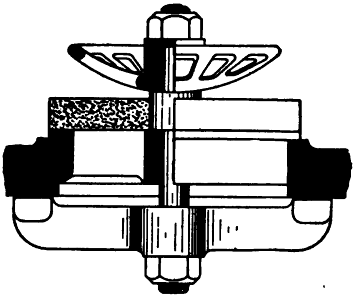

Fig. 28. Flexible Valve.

The valves of this type most commonly used are the 3-inch and the 4½-inch as the larger sizes are not found durable. The 3-inch valve is the best for ordinary use. The hole in the center is made $\frac{1}{16}$ to $\frac{1}{8}$ inch larger than the spindle to allow of free motion; furthermore to avoid sudden bending of the rubber, the guard is placed so as to give the disk a chance to rise about $\frac{3}{16}$ inch; and when it has risen this far, it bends around the guard and thus gives a free opening for the passage of the water. The guard should have a diameter equal to that of the disk less twice the thickness of the disk, and the radius of curvature should be equal to the diameter of the disk. This type of valve is not well suited for high pressures, 250 feet head being about the limit for the ordinary style. If, however, there are vanes arranged below the disk so that a rotary motion is given to

TABLE V

Flexible Valve Data

Diameter of Disk—Inches	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4	$4\frac{1}{2}$	5
Thickness of Disk—Inches	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{3}{4}$
Diameter of Hole in Center—Inches	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{11}{16}$	$\frac{11}{16}$	$\frac{13}{16}$	$\frac{13}{16}$

the valve, it is found that there is no difficulty in keeping the valve tight for heads up to 490 feet. For these pressures, it is not uncommon to use disks of a thickness up to an inch; but only for large sizes. The lap of the valve over the edge of the seat should be from $\frac{1}{4}$ to $\frac{1}{2}$ inch according to the thickness of the disk and the pressure to be carried.

Hinged Valves. The hinged valve, as its name implies, is made to swing about a pivot at one side. Leather valves have been used to some extent in the form of a simple flap fastened at one side and free to rise at the other; this makes the simplest form of hinged valve and, when weighted with a metal disk on either side, has been much used for small hand pumps, although it has not been found suitable for severe service. The more serviceable type with metal disk often has a facing of leather or rubber for slow speeds; but for high speeds these linings will not stand the wear. The hinged valve should be designed to lift from its seat before it begins to swing, the lift being about $\frac{1}{8}$ to $\frac{1}{4}$ inch. The angle to which the valve lifts is usually made 30 degrees, and, in order to ensure quick opening and closing, should never be over 60 degrees, the motion being limited by a stop on the seat or on the disk of the valve, Fig. 29. The hinged valve is slow in action and is not suitable for thick liquors or high pressures. In designing, the area allowed should be as given in Table VI.

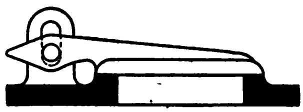

Fig. 29. Hinged Valve.

For higher speeds or for high pressures, it is best to use some form of positively driven valve, and, if such liquors as sewage or

TABLE VI

Hinged Valve Data

Piston speed, feet per minute.	100	125	150	175	200
Area of waterway, per cent of plunger area.	40	50	60	75	100

syrups are to be handled, the areas found in Table VI should be increased about 50 per cent.

Poppet Valves. The most common form of valve in use at present is the poppet which rises straight up from the seat and gives a free opening with a small motion. The seat is made either flat or at an angle of 45 degrees, as the designer may choose. The beveled seat is more difficult to construct, but retards the flow of water less than the flat seat, the latter necessitating a double turn in the current. The width of the beat or edge of the seat against which the valve rests is made $\frac{1}{4}$ inch for large valves and $\frac{1}{16}$ inch for small ones. The flow of the water through the valves should be at a velocity of not over 300 feet per minute, and the lift must be so proportioned that the passage by the valve will be as large as the area of the valve opening. A valve with flat seat need not have over $\frac{1}{4}$ inch lap even for heavy pressures, but the joint must be carefully made to avoid leakage.

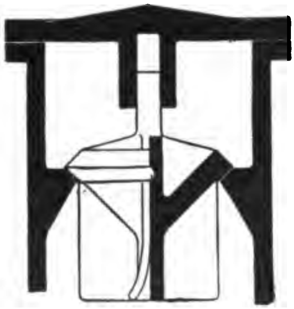
Fig. 30. Miter Valve.

A common form of *miter* or *beveled-seat valve* is shown in Fig. 30, and of *flat-seat valve*, in Fig. 31. The vanes on the bottom of the disk which keep the valve centered when it rises are often given an inclination of $\frac{1}{2}$ inch in 6 inches so that the rush of the water will give the valve a rotary motion which will remove all dirt and keep the wear on the seat even. For the flat seat valves this is not always possible as they are closed by a spring and the friction prevents them from revolving.

In order to give an area by the valve equal to the area of the seat, the lift must be one quarter the diameter of the seat opening. For heavy pressures this would make too large a lift, as the slip on closing would be excessive; for this reason the lift is made not over $\frac{1}{4}$ inch and the number of valves is increased as may be necessary. The seat is usually made separate from the valve deck and screwed into place. When this construction is used, the guide for a valve (if there is one) should

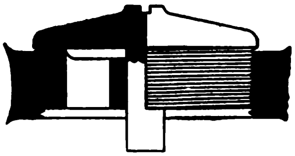
Fig. 31. Flat-Seat Valve.

be made a part of the seat so that the valve is self-contained. The guides may be in the form of wings on the bottom of the valve disk, a spindle running through a hole in the seat, or a spindle projecting upward through the valve; the last being most common.

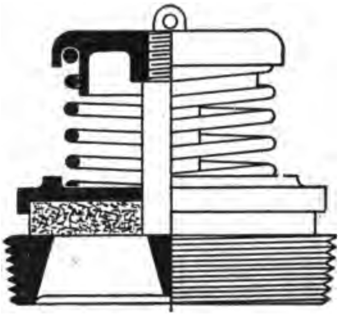
Fig. 32. Flat-Seat Valve—Approved Type.

The disks may be of metal or hard rubber. For hot liquids metal must be used, but for cold liquids hard rubber or composition is more common, usually with a metal cap to keep the disk in shape. The spring used for closing the valve should be cylindrical rather than conical, as the strain on the latter form comes largely at the small end of the spring and the wire is likely to break there. A design* to be recommended is that of Fig. 32.

Double-beat valves and those with multiple ports are not usually necessary but are sometimes used for large work.

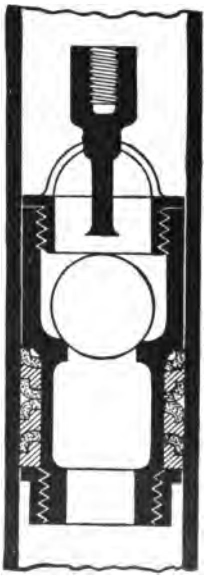
Fig. 33. Ball Valve.

Ball Valves. Ball valves are often used for low pressures. For these the diameter of the ball is made 1⅓ times the lift of the valve and a cage is provided so that the ball shall always be kept central. The ball is either of gun metal, usually with a rubber casing or, for cold water, sometimes wholly of rubber. Such valves are common in pumps used for mines and oil wells and often in connection with cup leather packings for the piston. If the water is gritty or has impurities, the valve seat should be raised above the deck so that there will be room for the sand to settle below the seat, as seen in Fig. 33.

In all valves which have metal for both disks and seats, it is important that they should both be of the same material, as otherwise there is likely to be galvanic action which will cause rapid deterioration. Usually, however, it is

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*See Barr's *Pumping Machinery,* Page 57.

TABLE VII

Spring Wire Sizes for Ball Valves

Diameter of valve, inches	2	2½	3	3½	4	4½
No. of wire B & S	12	12	10	10	8	8

better to use the valve with a separate disk of composition as this avoids all possibility of electrical action and makes the refacing of the valve unnecessary; the replacing of the old disk by a new one being all that is needed when the valve becomes worn.

For valves which are to be returned by a spring, it is best to use five coils in the spring and to have the wire of spring brass of the size given in Table VII.

In this style, it is well to use for the guiding spindle a stud screwed solidly into the valve seat or made a part of the casting, and fasten the valve by a nut at the top of the stud, secured by a pin. This is usually better than to use a stud screwed into the valve seat. If the latter is used, it is likely to work loose and may cause much damage before the trouble is discovered; it is also more difficult to remove when repairing the valve.

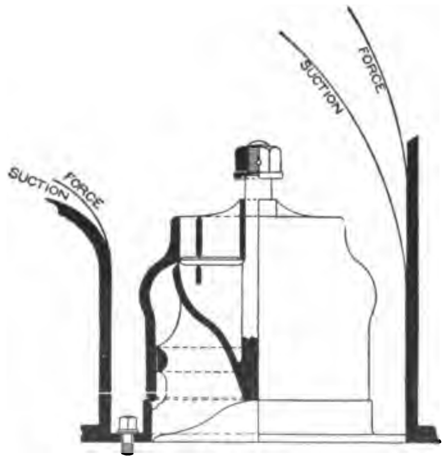


Fig. 34. Nagle Double-Feat Valve.

The material for the valve depends on the liquid to be handled. For acids or liquids of that nature, wood, although not durable, will last better than any form of metal; for salt, petroleum products, and strong alkalies, gun metal is the best; for all ordinary uses, however, cast iron is good enough, and if used with composition disks there will be no trouble from rusting fast even if the pump is idle for considerable periods.

The valves best adapted for large pumping engines are of the double-beat type, and usually of the "Cornish" form. A valve of this type, Fig. 34, designed by A. F. Nagle, has proved very satisfactory. The features embodied in this design are first, a small width of seat so as to avoid any possibility of sticking and to get rid of surface on which the pressure of the water cannot act to open the valve; second, a diameter large in comparison with the lift so that the velocity with which the water comes to the opening shall be small; third, a shape which avoids all sharp curves, all changes of direction, and all possibility of air pockets. The valve has been found to embody all these qualities, to work noiselessly even at high speeds, and to follow the motion of the piston almost exactly.

DESIGN AND CONSTRUCTION

The essential parts of a reciprocating pump are inlet and outlet valves, a cylinder, and piston or bucket. The purpose of each is obvious; however, in order to get the best results certain points must be considered in the arrangement and construction of these parts.

Valves. Some of the points concerning valves have already been mentioned on Page 29 Admission and outlet valves are usually of the same construction but sometimes differ in size, the outlet valves being smaller and more numerous so that the lift may be less and the slip under high pressures reduced. Valve decks are usually arranged, one for the inlet and one for the outlet valves; into these decks are screwed or bolted the valve seats, as already shown in Figs. 28 to 32, inclusive, the valves extending above into a valve chamber, Fig. 24. The valves should have space enough between them and between the outside valves and the walls of the valve chamber so that the area for the passage of the water shall equal that through the valve openings. Generally, considerations of strength of the valve deck also demand as wide spacing as does the necessary water-way.

Cylinder. The design of the cylinder depends entirely on the kind of pump, the considerations involved having already been mentioned. For a small and compact machine, the piston type is the best and this calls for a smoothly-bored barrel. In order that this may be easily renewed, it is usual to make the bored portion as a lining which fits an outer casting, Fig. 24, so that when worn by grit or long use, the lining may be renewed without remaking the whole water end.

If there is much sand or dirt in the water, it is usually better to use some form of plunger pump, as the round-turned plunger is much cheaper to renew than the bored-barrel lining; also the cylinder will be cheaper as there is little boring to be performed. The difficulty of an inside packed plunger has been mentioned and also the alternative of a double plunger, outside packed, Fig. 25 and Fig. 26. In spite of the difficulty of ascertaining and stopping leakage past the piston, and the expense of boring and reboring or relining the cylinder, the piston pump is used, except for high pressure, more than any other form on account of its compactness.

Clearance. At the end of the cylinder there is a space into which the piston or plunger does not travel. It is not, as is the case with the steam engine, a source of loss, hence it is advisable to provide a generous amount of clearance so that there will be a place for grit or foreign matter to settle, and no possible chance of the piston striking the cylinder head.

Bucket. The bucket is rarely used except in vertical pumps and then almost entirely for mine or well purposes. It is of the form shown in Fig. 33 with possibly the flat seat valve in place of the ball. The outside of the bucket is packed by cup leathers or by hemp packing, the same as a piston, or it may simply have grooves turned in the outside to form a water packing. The barrel is often simply a brass pipe, bored to make a fit, and screwed to the end of the vertical pipe so that it may be easily renewed. In the case of deep wells, the bucket should be made with a long bearing surface so that it may the more easily keep a water-tight joint and may act as a steadier to keep the pump rod in line.

Piston. The *piston rod* for a pump is made much larger than considerations of strength would seem to demand, in order that there may be no vibration or deflection, as these would make it almost impossible to keep the stuffing-box from leaking. Theoretically the rod for a long-stroke pump should be larger than that for a short stroke of the same diameter; but, actually, the margin of strength is so great that the same size rod will answer for both. Allowance must be made in all cases for the reduction in diameter necessary to fasten the piston or plunger to the rod. This may be done by using a tapered end fitting a tapered hole in the body of the piston or by turning down the end of the rod and letting the piston bear against a shoulder; the latter method is the better. Usually a nut

TABLE VIII

Sizes of Piston Rods

Piston Diameter—Inches	4	6	8	10	12	14
Rod Diameter—Inches	1⅜	1⅝	1⅞	2¼	2⅜	2½
Diameter of Rod End—Inches	1⅛	1⅜	1½	1¾	1¾	2

holds the piston in place, the nut being, in turn, secured by a lock nut or split pin through the end of the rod. Various modifications of these methods are of course used according to the fancy of the designer.

The diameters of piston and corresponding rod for a rod of cold rolled steel, tensile strength 65,000 pounds, a factor of safety of 10, and a pressure of 150 pounds are given in Table VIII.

Packing. The water end of the pump is necessarily long, as the piston must be of such length that it can be packed, and usually with some kind of soft packing such as flax, hemp, or leather. Fig. 35 shows the detail of a piston designed for use with square flax packing; the body is fastened to the piston rod by the nut *A*, the packing laid in place, and the follower forced up by the nut *B* which is, in turn, secured in place by the lock nut *C*. For large sizes, the design is the same except that the follower is set up by a number of nuts screwed onto stud bolts near its edge.

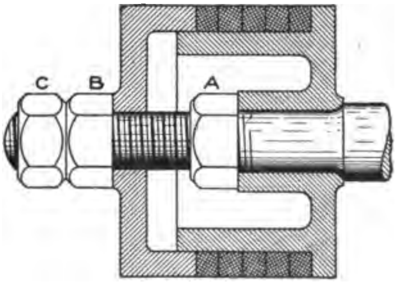


Fig. 35. Square Flax Packing.

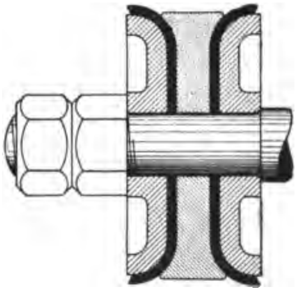


Fig. 36. Leather Packing.

A *leather-packed piston* is shown in Fig. 36. The packing is made by pressing sheets of wet leather into iron forms and allowing them to dry there, after which the edges are finished. The radius of the corner must be large, so that the leather will not be injured in the pressing process, about ½ to ¾ inch being sufficient. The diameter of the disk from which the cup is formed need not be more than 1¼ to 1⅝ inches greater than that of the piston, as there is no object in having the lip of the cup longer than to make a tight joint.

Less common forms of piston packing are the *metal ring* and the *groove* packing. For the former, the ring, which is sprung into place, should be made about $\frac{1}{8}$ inch larger than the piston for a 12-inch piston; other sizes in proportion. For the groove packing, the grooves are best made about $\frac{3}{8}$ inch deep by $\frac{1}{4}$ inch wide. If soft packing is used, the length of a piece cut for a ring should be somewhat less than that needed to have the ends meet when placed around the piston body, in order to allow for the swelling of the packing as it becomes wet. One rule is to make the space between ends equal to the width of the packing.

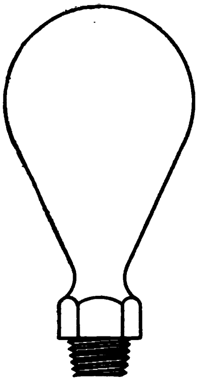


Fig. 37. Air Chamber

The piston is packed the same as a stuffing-box, the rings, arranged so as to break joints, being put in with a stick of soft wood and forced home. Coating the packing with cylinder oil and graphite will be found to give good joints, easy action, and easy removal. It is well to keep a few rings of packing on hand ready cut so that when examining a piston new rings may be inserted if necessary for a quick repair and to soak the packing a few hours in hot water just before inserting.

Plunger. For a plunger, a hollow casting is generally used; the only requirement being that the thickness shall be sufficient to withstand the pressure against which the pump acts. The length must, of course, be equal to the stroke plus the length of the stuffing-box and an amount sufficient to insure that the head of the plunger will never strike the gland. A plunger is sometimes used with an open end and the partition set back into the interior of the plunger, but this is not as strong a construction as the closed-end type and is more expensive to make.

Air Chamber. With single-cylinder pumps it is customary to use an air chamber on the discharge to steady the flow of the water and to prevent shock, but for those having several cylinders this is not considered necessary. Even if the motion is slow and the pressure against which the pump works is great, it is better to use the air chamber even with multiple cylinders, and it is often

TABLE IX

Dimensions of Air Chamber

Diameter—inches	6	8	9	10
Height—inches	10	14	15	16
Pipe-tap Thread—inches	1	1¼	1½	2

advisable for fast running pumps or those with a long suction pipe to use an air chamber on the suction side as well. The volume of the discharge chamber should be three to four times that of the piston, or plunger, displacement per stroke, and for the suction chamber twice such displacement if the pump is single. For duplex pumps, ⅓ to ½ less will answer. The neck of the chamber is made long and narrow so that the air will not easily escape and the flow of water in and out will be somewhat retarded. For small sizes the chamber is made of copper in a standard form, Fig. 37, the dimensions being given in Table IX.

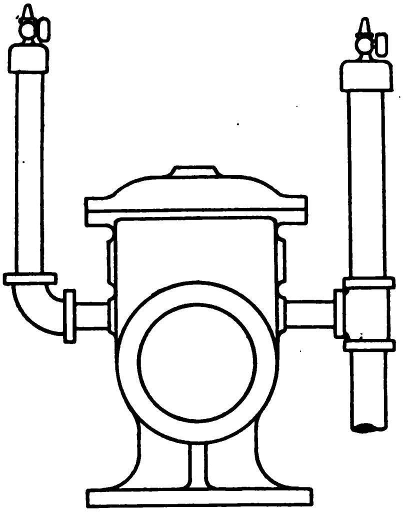


Fig. 38. Proper Location of Air-Suction Chamber

For larger sizes a casting is used with straight sides and a hemispherical top as shown in Fig. 25. For this style a common proportion is to make the height three times the diameter and the diameter of the neck one-third that of the chamber proper.

The air chamber on the discharge should be placed at the highest point of the valve chest and above the delivery opening so that the air will not tend to slip out with the water. Even then, the air will gradually be absorbed by the water, and the air cushion must be renewed either when the pump is not in use by admitting air through a cock and allowing some water to escape from the valve chest, or continuously by an automatic pump.

The suction air chamber should be so placed that the stream of water flowing to the pump may cushion against the air in it without abruptly changing its direction. Two positions which fulfill this condition are shown in Fig. 38. If it is impossible to place the suction chamber in such a position, the capacity should be increased, the amount depending on the speed at which the pump is to be run.

In designing the valve chest, flat surfaces should be avoided, as they are not adapted to resist pressure. A rounded or oval surface gives greater strength and will more easily conform to the outline presented by the valve studs and the top of the chest. A good design is shown in Fig. 24.

Ports. The ports or valve openings and the passages from the valve chests to the cylinder should be large enough so that the velocity of the water when the pump is working at its greatest speed will be not over 300 feet per minute. The ports should be short and direct to avoid friction and, if possible, should be so arranged that the water passes into, through, and away from the pump without changing the direction of its motion. This last condition usually conflicts with the necessity of placing the valves so that they are readily accessible and is, therefore, disregarded by many makers.

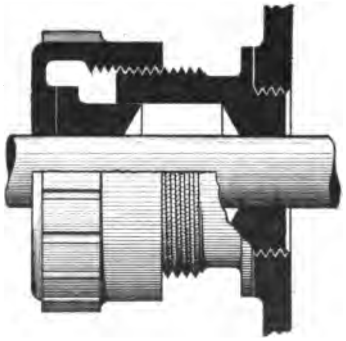


Fig. 39. Stuffing-Box with Screw Cap

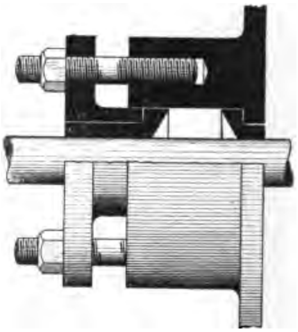


Fig. 40. Stuffing-Box for Large Piston Rods

Stuffing-Box. The stuffing-box for rods 1 inch or less in diameter is made with a cap to screw over the end of the box in order to force in the gland, Fig. 39. For larger sizes the gland is forced by nuts screwed on stud bolts which pass through a flange on the gland, Fig. 40. The gland and box may be bushed with brass or made of solid iron. The box should be made deep enough to allow four rings of packing and should preferably have the bottom and end of the gland chamfered in order to force the packing against the rod and make a more secure joint.

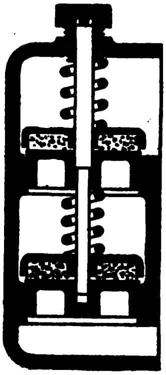


Fig. 41. Valve Chambers in Cameron Pump

Frames. The frame or body of the pump is to hold all parts together and keep them rigidly in position. With this end in view, it pays to use enough iron to make the frame massive, yet it should be so distributed as to be of the most use. The standards or legs should be of good length so that the pump may stand well away from the foundation and be accessible. The feet should have a large surface to secure stability and good bearing. For pumps which are to work against high pressures, round chambers connected by round passageways should be used for the valve chambers. The valve chambers should be so arranged that the valves or seats may be easily removed and replaced, a convenient arrangement being that of Fig. 24 where the inlet valves are directly under the outlet valves, hence can be readily examined. Details of such an arrangement, as used in the Cameron and Davidson pumps, are seen in Figs. 41 and 42, respectively.

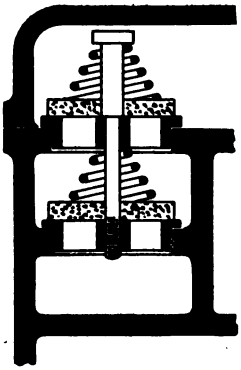


Fig. 42. Valve Chambers in Davidson Pump

Pump Ends. Pump ends are made of four general specifications, according to the purposes for which they are to be used. In the *all-iron* pumps the valve seats are malleable iron, the springs are of steel, the cylinder bore is not lined, and the rod nuts are of iron. This type is used for such liquids as ammonia, tar, caustic soda, and milk of lime, where brass or bronze is affected by the material handled and is therefore not permissible.

The *regular fitted* pump has the piston, or plunger, of cast iron, the piston rod of steel, the cylinder bronze lined, and the valve seats, springs, and nuts of bronze. The valves are of material suitable for the purpose of the pump as explained under the subject of valves. This type of pump is ordinarily used for water and other liquids not requiring special treatment.

The third class of pump—*bronze-fitted* pump—has the piston of bronze or bronze lined, the piston rod of bronze, the stuffing-box and glands bronze or bronze lined, the cylinder with bronze lining, the valve seats and nuts of bronze, and usually the valves of bronze. This is used for tan liquor, beer, brine, oil, salt water or sewage, or for other purposes where iron or steel would be affected by the liquid handled.

The *all-bronze* pump is made with all parts of bronze, no iron or steel being used, and is for handling such liquids as will attack iron or steel but will not attack bronze.

For special purposes, where the pumps must be carefully protected from all action of acids or similar liquors, a lead or wood lining may be used, all surfaces being covered by either lead or wood. Such a lining may also be used where it is particularly desired that the liquid handled shall be protected from any possible taste due to contact with a metal.

Arrangement of Parts. The arrangement of the parts of a pump is the test of a designer's skill. Air pockets must be avoided in the cylinder or clearance spaces by so designing the passage through the cylinder that the water may leave at the highest point of the chamber and the air may not be caught in any recesses. Air pockets in the discharge valve chamber are not serious, but in the inlet valve chamber they will result in lost motion.

Almost all small horizontal pumps are arranged with both the inlet and discharge valve chambers above the cylinder, as this makes all valves readily accessible and gives a compact water end. Unquestionably, smoother action and a more efficient pump would be obtained if the admission valves were placed below the cylinder, so that the water need not reverse its direction of flow while passing through the pump; but it is a case for judicious compromise, and the common arrangement gives good service so long as the speed of working is slow.

The suction pipe usually comes in at one side, and the discharge pipe leaves directly above it on the same side, Fig. 43, or on the side opposite. Fig. 43 is a single-cylinder pump.

For the direct-acting steam pump, the steam and water cylinders must have their axes coincident. The two cylinders should be placed as near each other as is consistent with provision for the valve gear and room to care for the stuffing-boxes. Compactness is desirable, but convenience in caring for the pump and in making repairs is much more essential. At the lowest point on each cylinder end provide a drain cock with which to draw off all water when the pump is shut down in order to prevent rusting, pitting, or freezing.

Proportion of Parts. *Size of Piston.* The size of the piston or plunger and the length of stroke are determined by the capacity desired. The allowable speed of piston is often stated at 100 double strokes per minute, but 60 double strokes per minute is a better limit, as the determining factor is really the time needed for reversal and for change of valves at the end of the stroke. For small pumps, the limit might be made 100 double strokes per minute, but the smaller number is better. At 60 double strokes or 120 single strokes per minute the piston speed in feet per minute will be

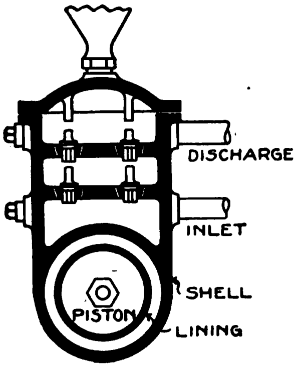


Fig. 43. Cross-Section of Single-Cylinder Pump.

$$\frac{l \times 120}{12} = 10\,l$$

where l is the stroke in inches; and for 100 double strokes the speed will be $\frac{10}{6}$ times the above value, or 16.7 l. For pumps of over 6-inch stroke this higher limit is not advisable.

In Table X may be found the capacity of any size pump at a speed of 60 strokes per minute, or the diameter and corresponding length of stroke needed to move any given number of gallons per minute, no allowance being made for slip. To find the capacity at any other speed, divide the given capacity by 60 and multiply by the number of double strokes at which the pump is to run. Thus suppose it is desired to find the capacity of a pump of 3-inch diameter by 4-inch stroke at 80 double strokes.

The capacity at 60 double strokes is 14.7 and at 80 it will be

$$\frac{14.7}{60} \times 80 = 19.6 \text{ gallons per minute}$$

The ratio of stroke to diameter may be chosen by the designer, the value in standard designs running from 2:1 to 1:1.25, the more common being 3:2 and 1:1.

TABLE X

Capacity of Pumps in Gallons Per Minute at 60 Double Strokes Per Minute

Diameter in Inches	Stroke in Inches														
	2	3	4	5	6	7	8	9	10	12	14	16	18	20	24
1	0.81	1.21	1.63	2.02	2.42	2.85	3.26	3.68	4.10	4.90	5.70	6.52	7.36	8.20	9.80
2	3.26	4.89	6.52	8.15	9.78	11.41	13.04	14.67	16 30	19.56	22.82	26.08	29.34	32.60	39.12
2½	5.06	7.63	10.18	12.72	15.27	17.81	20.36	22.90	25 45	39.54	35.63	40.72	45.81	50.90	61.08
3	7.34	11.01	14.68	18.35	22.02	25.69	29.36	33.03	36.70	44.04	51.38	58.72	66.06	73.40	88.08
3½	9.95	15.00	20.00	25.0	30.00	35.00	40.00	45	50	60	70	80	90	100	120
4	13.1	19.6	26.2	32.6	39.2	45.8	52.2	58.9	65.3	78.4	91.6	104.4	117.8	130.6	156.8
4½	16.6	24.8	33.0	41.3	49.5	57.8	66.1	74.4	82.5	99.0	115.6	132.2	148.8	165.0	193.0
5	22.0	30.6	40.8	50.9	61.1	71.3	81.5	91.6	101.8	122.2	142.6	163.0	183.2	203.6	244.4
6	29.4	44.0	58.8	73.4	88.0	103	117.6	132.3	146.8	176.0	206	235.0	264.6	203.6	352.0
7	39.9	60	79.8	100	120	140	160	180	200	240	280	320	360	400	480
8	52.2	78.4	104.4	130.8	156.8	183	208.8	234.8	261.6	313.6	366	417.6	469.6	523.2	627.2
9	66.1	99.2	132.2	165	198.4	237	264	297	330	396.8	474	528	594	660	793
10	81.5	122.4	163	204	244.8	286	326	367	408	489	572	652	734	816	978
12	117.6	176	235.2	293.6	352	412	470	529	587	704	824	940	1058	1174	1408
14	160	240	320	400	480	560	640	720	800	960	1120	1280	1440	1600	1920
16	209	313	418	523	626	732	836	939	1046	1252	1464	1672	1878	2092	2504
18	264	397	528	660	794	948	1056	1188	1320	1588	1896	2112	2376	2640	3176
20	326	489	652	816	978	1144	1304	1468	1632	1956	2288	2608	2936	3264	3912
22	395	591	790	988	1180	1380	1580	1780	1978	2360	2760	3160	3560	3956	2720
24	470	704	940	1174	1408	1648	1880	2116	2348	2816	3290	3760	4232	4696	4832

TABLE XI

Allowance for Slip

Class of Pump	Slip in Per Cent of Volume Pumped	
	At High Speed	At Low Speed
Small centrifugal	75	60
Medium centrifugal	50	40
Fire engines	40	30
Large centrifugal	25	15
Triplex power	22	18
Lift and drainage	15	10
Ordinary piston	18	15
Mine and deep-well pumps	15	12
Waterworks	6	4

The first value to be found is the amount of water to be handled per minute, and this will usually be determined by the work for which the pump is to be used. The allowance for slip, *i. e.*, the loss due to slow closing of the valves and leakage, must then be added before the size of the water end can be settled.

The slip depends on the style of valve used, the size of pump, and the speed at which it runs. Approximate values are shown in Table XI.

The size of a pump to move a given volume of water may now be determined. Suppose, for example, that it is required to force 200,000 pounds of water through a condenser per hour. This, at 8.338 pounds per gallon, would be 23,987 gallons per hour, or 400 per minute, if there were no slip; but for a common lift pump 10 per cent must be allowed so that the capacity must be for $400 \times 1.10 = 440$ gallons per minute. From Table X this would require a 10 × 12, a 9 × 14, or an 8 × 18; the 10 × 12 would be the most common proportion.

NOTE. — In giving the dimensions of a steam pump the diameter of the steam cylinder is given first, then the diameter of the water cylinder, and finally the length of stroke, which is, of course, the same for both. For example: 16 × 9 × 12 means—16 inches diameter of steam cylinder, 9 inches diameter of water cylinder, and 12 inches length of stroke.

Area of Valves. The area of valves should be such that the velocity of the water through them will not exceed 250 feet per minute; for 440 gallons, the volume would be $\frac{440 \times 231}{1728} = 58.8$ cubic feet.

At 250 feet per minute, the valve area $= \frac{58.8}{250} = .2352$ square feet, or practically 34 square inches. The area of a 3-inch valve is 7 square inches, so that the five valves would be sufficient. The circumference is 9.42 inches; this gives a lift of $\frac{34}{5 \times 9.4} = .723$ inch, an amount perhaps not too great for smooth action at the low pressure of a condenser pump; but it would be better even for this service to use twelve 2-inch valves, giving a lift of .45 inch.

Power Required. To find the power required, it is necessary to know the pressure against which the pump is to act both for suction and forcing. Assume this to be, in the present case, 5 feet of suction head and 5 pounds pressure due to the friction in piping and condenser tubing; the total pressure will then be 7.16 pounds per square inch, and on the 10-inch piston the total force would be $78.54 \times 7.16 = 562$ pounds. The pump is to make 120 strokes per minute, each stroke being 12 inches, or one foot long, so that the work per minute would be $120 \times 562 = 67{,}440$ foot pounds, and the power $67{,}440 \div 33{,}000 = 2.04$ horse-power provided there were no friction. It is customary to allow 25 per cent for friction in pumps, which would increase the power required to $2.04 \times 1.25 = 2.55$ horse-power.

Size of Steam Piston. To find the diameter of steam piston needed, the steam pressure must be known and the foregoing process can then be reversed. Assume the pressure to be 80 pounds; the work per minute is $2.55 \times 33{,}000 = 84{,}000$ foot pounds, which, at 120 feet per minute, would require a force of 700 pounds, and, at 80 pounds per square inch, an area of $\frac{700}{80} = 8.75$ square inches, corresponding to about a $3\frac{3}{8}$-inch diameter. Usually the steam and water ends are made much more nearly the same size than this would indicate and the steam throttled between the boiler and the steam end of the pump, so that the pump may be adaptable to a wide range of conditions.

Miscellaneous. The parts of a pump should be proportioned to withstand the forces which are to come on them, not only without danger of breaking, but without bending. For the parts which are to be of cast iron, such as cylinder, valve-chests, and frame, the consideration which decides the dimensions is often the thickness of metal which will cast well; while for the piston it is the length which will give a good *bearing surface* on the cylinder to resist wear, and a *tight joint* to prevent leakage. These points are largely matters of experience and good judgment, but some ideas can be given as to common practice.

For a *packed piston,* usually 4 rings of ¾-inch square packing are used. Common values of *rod diameters* are given in Table VIII. In designing the *body and follower* of the piston, it should be remembered that the less weight the better so long as the strength is sufficient; but a piece of cast iron less than ⅜-inch thick seldom casts well in any complicated casting.

For the cylinder, the same equation may well be used for both steam and water ends. Whitham gives, allowing for strength, rigidity, and possible reboring

$$t = .03\sqrt{P\ D}$$

where P is the maximum pressure in the cylinder in pounds per square inch; D, the diameter in inches; and t, the thickness of the cylinder walls. *The length of the cylinder* will be the length of stroke plus the length of piston and fastening nuts plus twice the clearance at one end, which should be at least ½ inch. The clearance should be counterbored to leave the length of the bore somewhat less than the length of stroke plus the length of piston. The soft packing or piston rings should not, however, be allowed to run into the counterbore. An average of various formulas for the thickness of cylinder heads and flanges as given by Kent, is

$$t = .00036\,P\,D + .31 \text{ inches}$$

The flanges on the cylinder are made of the same thickness as those on the cylinder head.

For large cylinders it is usual to support the head by ribs running from the center to the circumference, though some designers consider this bad practice. The flange through which the bolts pass is made ⅓ thicker than the thickness of heads given by the above formula. To avoid springing of the flanges, cylinder-head bolts should be so spaced that the distance on centers will be not over 4 to 5 times the thickness of the flanges. The diameter should be such that the stress in the bolts will be less than 5,000 pounds per square inch. If N is the number of bolts and d their diameter

$$N \times \frac{\pi d^2}{4} \times 5000 = \frac{\pi D^2}{4} P$$

simplifying

$$d = D\sqrt{\frac{P}{5000\ N}}$$

The *area of inlet and discharge ports and pipes* should be at least equal to that of the valves.

The *thickness of the walls of the valve chambers* is usually a little greater than that of the cylinder walls. For high-pressure pumps it is best to give these chambers as nearly as possible a cylindrical form in order to secure the greatest strength for a given weight of material.

For the *frame,* it is impossible to give any rules or suggestions except that the student should get catalogues from the prominent makers and study them to see what has been found satisfactory.

For proportioning the *driving end* of a pump, whether steam-, belt-, or motor-driven, the ordinary rules for the kind of machinery involved apply. However, it should be remembered that the parts are subjected to severe shock on the reversal of the pump, hence a factor of safety as high as 15 should be used.

Where pumps are required for *special service,* the amount of water to be pumped per hour is generally fixed by the conditions of the service; but for a few cases the method of determining that amount can be definitely given. For a boiler-feed pump, it is necessary to know the horse-power of the boilers to be cared for by the pump. One boiler horse-power will call for the handling of 30 pounds of water per hour, and the pump should be specified accordingly with an allowance for good measure. The amount of air and condensed steam which an air pump may be called upon to handle is difficult to estimate, hence, a common rule is to make the volume of the double-acting air-pump cylinder $\frac{1}{10}$ that of the low-pressure cylinder of the engine which it is to serve. The double-acting circulating pump has a volume about $\frac{1}{35}$ that of the low-pressure cylinder, or it may be figured from the horse-power of the engine, assuming the steam consumption at 25 pounds per I. H. P. per hour, and the cooling water at 30 pounds per pound of steam. Of course, for accurate calculation, the steam consumption would vary with the size and type of engine, but the above will give safe average values.

TYPES

The different types of reciprocating pumps may be classified as follows:

Arrangement of Water End	Single Duplex Triplex
Method of Driving	Direct-Acting Belt-Driven Motor-Driven
Special	Combined-Condenser Dry Vacuum Compressed-Air

The single, duplex, or triplex arrangement depends on whether one, two, or three cylinders are assembled into a single machine drawing water from the same suction inlet and discharging it into the same outlet. The difference between single-acting and double-acting pumps has already been noted.

Single Pumps. The single cylinder is much used for small sizes of pumps or where constancy of flow is of minor importance.

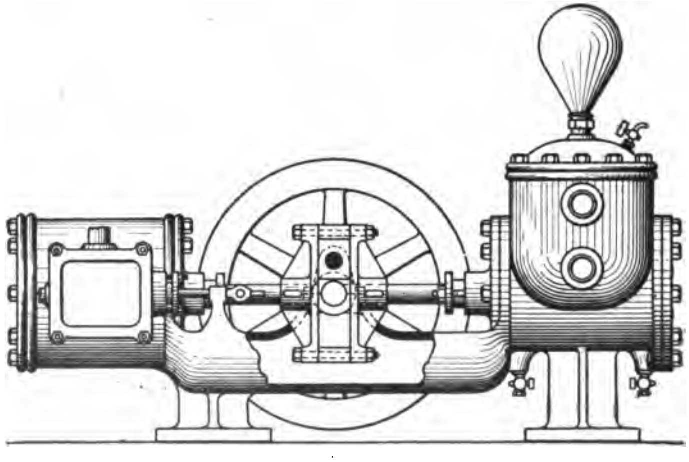


Fig. 44. Single Pump—Designed for Fire Engine Use.

It is, of course, the cheapest arrangement and gives satisfactory results if the pump is of ample size for the work. A difficulty with this type of pump is that of providing a means of operating the steam valve to reverse the motion of the piston at the end of the stroke. The pistons in steam and water cylinders must be stopped gradually to avoid pounding, and this leaves no force available just at the end of the stroke when it is needed to move the steam valve so as to reverse the motion.

The difficulty has been overcome in two ways: first, by the introduction of a shaft and fly wheel, and second, by means of an auxiliary valve and steam-driven main valve. The fly wheel is driven by a crank and a yoke in the rod between the steam and water cylinders, Fig. 44. The inertia of the fly wheel then furnishes the force needed to move the valve at the instant of reversal, generally by means of an eccentric on the shaft. This form is often used for fire-engines, two or three sets of cylinders sometimes being connected to one shaft, in which case the pump becomes of duplex or triplex form. For stationary pumps, the fly wheel and shaft are more commonly placed beyond the cylinders at one end of the frame, and the shaft is driven by a crank and connecting-rod mechanism from a crosshead attached to the piston rod, Fig. 45. The fly wheel also makes it possible to use steam expansively. The second method is generally made use of on small, single-cylinder, direct-acting pumps for boiler feeding, tank filling, and similar uses.

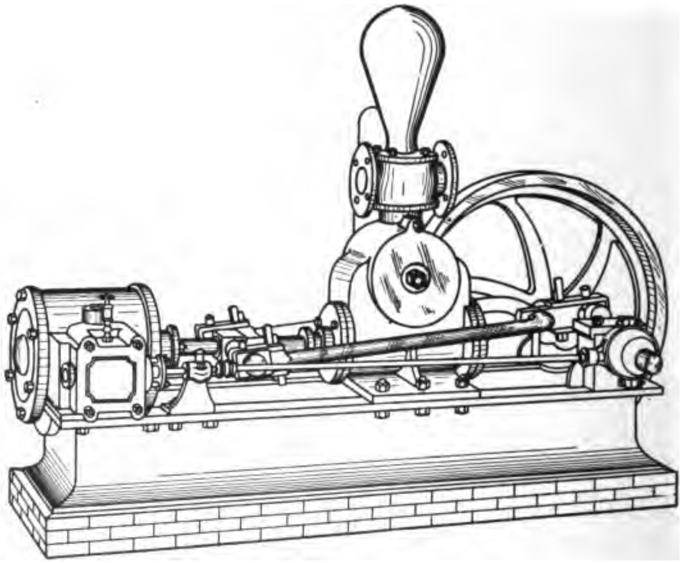


Fig. 45. Single Pump—Stationary Type.

The single pump is compact, cheap, and convenient, but the flow of water is by a series of impulses rather than in a steady stream, so that, if the pump is forced, it slams badly and produces water hammer, an evil which is only partially remedied by the use of discharge and suction air chambers.

Duplex Pumps. To avoid this, and at the same time to simplify the moving of the steam valve, the late Henry R. Worthington devised the duplex form, in which two direct-acting pumps are mounted side by side, the water ends and the steam ends working in parallel between inlet and exhaust pipes as seen in Fig. 46. The steam valve for cylinder A is moved by a bell-crank lever driven from the rod of cylinder B as it nears the end of its stroke; so that, when the piston of B is about to come to rest, that of A is set in motion. While the

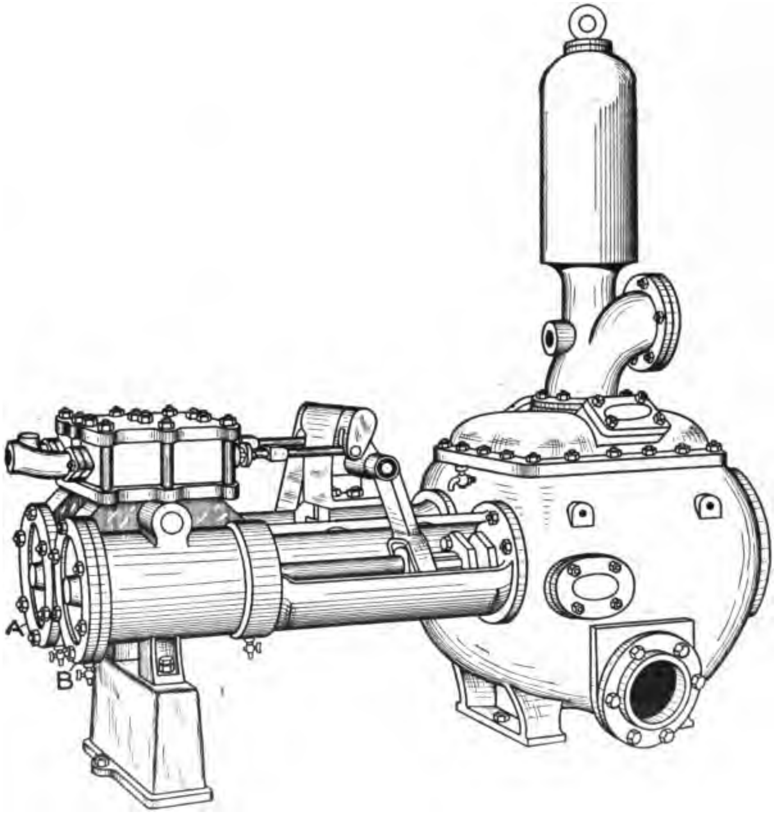


Fig. 46. Duplex Direct-Acting Pump.

piston of *A* makes its stroke, that of *B* is at rest until that of *A*, near the end of its stroke, moves the steam valve of cylinder *B* by means of a second bell-crank lever, and the piston of *B* is once more set in motion. Thus the pistons move alternately, but one or the other is always in motion and the flow of water is made practically continuous.

Single vs. Duplex. As between the single-cylinder pump and the duplex type the arguments may be summarized as follows: The single-cylinder pump must stop during reversal, and this means the stopping of the flow of the column of water in both the suction and discharge pipes; this may in part be remedied by the use of air chambers, which, however, tend to reduce the capacity of the pump. For high pressures the air will be rapidly absorbed and the absence of air in the chamber will result in shocks and water hammer. The single-cylinder pump, carefully set to give the maximum stroke, has less steam loss in the clearance spaces and by the action of the auxiliary valve the length of the stroke is definite, regardless of rod friction, while in the duplex pump any friction on the piston, piston rod, or valve rod may result in short stroking with reduced capacity of the pump and increased loss of steam in the clearance spaces. The single cylinder has few parts to keep in proper condition, few joints to leak, and small radiating surface, while the duplex has a simple valve gear, and cannot stall, even when run at very low speeds.

Because of these characteristics the single-cylinder pump is particularly well adapted for wet-vacuum and air pumps, since a considerable part of the work on the pump end is the handling of air and vapor and short stroking or large clearance materially reduces the pump-end capacity; for the handling of high pressures, and especially with high or very slow velocity of flow, the duplex type, on account of its more nearly continuous action, is often preferred. See Table XII for data on both types.

Fire Pumps. Fire pumps are designed to start instantly after long disuse; must be duplex, with cross-operated valves; should preferably be of plunger pattern; must be brass-fitted throughout; should be designed to carry a water pressure of 320 pounds; the suction-valve area should not be less than 50 per cent of the plunger area for a 10-inch stroke and 56 per cent for a

TABLE XII

Maximum Capacities of Pumps for Boiler Feeding

(Boiler Horse-Power of 30 Pounds per Hour)

Diam. (in.)	Stroke (in.)	Single Cylinder	Duplex Cylinder	Diam. (in.)	Stroke (in.)	Single Cylinder	Duplex Cylinder
2	3		45	6	10		1400
2	4	50	75	6	12	850	1500
3	5		190	7	10		1850
3	6	130		7	12	1200	2200
3½	5		240	8	12	1400	2700
3½	6	175	270	8½	12	1800	3000
4	6		500	9	12		3200
4	7	250		10	12		4000
4	8	300	550	10	16	2500	
4½	10	400	750	10	18	2600	
5	6		650	10	20	2700	
5	10	500	900	12	15		5200
5½	12	650		12	20	3750	

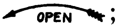
12-inch stroke; the discharge valve area should not be less than ⅔ of the suction-valve area; valve springs should be cylindrical, not conical, and should be held at the ends in a groove; studs should be so designed as to always allow a lift of ⅕ of the valve diameter; valve seats should be of gun metal held in the deck by a taper thread; the least area of exhaust passage should be 4 per cent of piston area; admission ports should not be less than 2½ per cent of piston area; clearances should be as small as possible; valve tappets should be nonadjustable; cushion valves controlling a by-pass from steam to exhaust port to regulate the amount of steam cushion at ends of stroke are recommended for 750- and 1,000-gallon pumps; a gauge should be provided which will show at all times the length of stroke that the pump is making; a water-pressure gauge with a ¼-inch lever cock should be connected close to the air chamber; a relief valve of Ashton, Crosby, or of similar pattern, and of size sufficient to discharge the full throw of the pump working at ⅔ speed should be furnished and set to 100 pounds pressure; this valve should have a hand wheel conspicuously marked showing the direction to ; the relief valve should discharge downward into a vertical pipe, thence into a funnel; ⅜-inch brass drip cocks with lever handles should be on both ends of the steam and water cylinders; a ¼-inch lever air-cock should be on the cover over the water cylinders; each pump should be fitted

TABLE XIII

Dimensions and Capacities of Fire Pumps

No. of 1⅛-Inch Streams	Capacity Gals. Per Min.	Ratio of Piston Areas	Boiler H. P. Needed	Steam Press. Needed at Pump. Lbs. Per Sq. In.	Nearest Commercial Size, Inches		
					Diam. Steam Cylinder	Diam. Water Cylinder	Stroke
One (Too small except for auxiliary.)	320	4 to 1	. . .	40	10 12 10 12	5 6 5 6	10 10 12 12
Two (For small mills.)	500	4 to 1	100	40	16 14	8 7	10 12
Three (For general use.)	750	3 to 1	115	48	16 16	9¼ 9	10 12
Four (For large factories.)	1,000	3 to 1	150	44	18½ 18	10½ 10	10 12

For over 1,000 gallons per minute, two pumps should be used.

Capacity Gal. Per Minute	Diameter of Pipes in Inches				Capacity Gallons		Diameter Relief Valve Inches
	Suction	Discharge	Steam	Exhaust	Air Chamber	Suct. Cham.	
320	6	5	2½	3	10	8	2½
500	8	6	3	4	17	13	3
750	10	7	3½	4	25	18	3½
1.000	12	8	4	5	30	24	4

with brass priming pipe, starting with a 2×1×1 inch brass tee close to the pump beneath the delivery flange and leading to four $\frac{3}{4}$-inch valves, one opening to each of the four plunger chambers; a priming tank should be provided with bottom at least 5 feet above the pump, and should have a capacity half that of the pump in gallons per minute, unless water flows to the pump under pressure; the priming tank must be used only for that purpose; each pump should be fitted for hose connections as per number of streams to be served; capacity of cylinders, sizes of piping, air and suction chambers, and relief valves should be as per Table XIII.

A special acceptance test is demanded as follows: The pump must run smoothly, without slamming, at its full rated speed; must maintain a water pressure of 100 pounds per square inch when furnished with steam at a pressure of 45 pounds for the 500-gallon pump, 50 pounds for the 750-gallon pump, 55 pounds for the 1,000-gallon pump; the water must be discharged through $1\frac{1}{8}$-inch nozzles on hose lines 150 feet long; the hose must lie quietly, showing uniform delivery; with all water outlets closed and steam supplied to give 80 pounds water pressure, leakage must not allow the pump to make more than one double stroke per minute; with the water outlets nearly closed, the pump when running slowly, must carry water pressure of 240 pounds per square inch and all joints must remain practically tight; with relief valve set at 100 pounds and all other outlets closed, the pump must discharge full delivery at 50 double strokes per minute with the water pressure rising to not over 125 pounds. Although these specifications appear rather rigid, the emergency element in the use of the fire pump makes it imperative that first-class design and construction be used.

On the inboard side of the air chamber must be placed a name plate bearing data in black enamel letters $\frac{1}{2}$ inch high on a white enamel ground, of which the following is an example:

Diameter of cylinders and stroke, 16×9×12; capacity in gallons per minute, 750, or three $1\frac{1}{8}$-inch smooth nozzle streams; full speed, 70 revolutions (double strokes). "For Fire purposes never let steam get below 50 pounds, nights or Sundays."

Triplex Pumps. The triplex pump is generally used for power pumps. The pistons, or plungers, are driven from a shaft by three cranks or eccentrics, set at 120 degrees to each other so that the

TABLE XIV

Approximate Horse-Power Requirements, Speeds, and Pulley Sizes for Triplex Single-Acting Power Pumps

Size of Pump (inches)	H.P. per 100 Lb. Pres.	Speed R.P.M.	Pulley Dimensions	Size of Pump (inches)	H.P. per 100 Lb. Pres.	Speed R.P.M.	Pulley Dimensions
1¼ x 2	0.30	65	12 x 1½	10 x 10	31.00	45	42 x 8
2 x 2	0.32	65	12 x 2	12 x 10	44.60	45	
1¾ x 2½	0.40	65	12 x 2	3½ x 12	3.45	42	
2 x 3	0.70	60	12 x 2½	4 x 12	5.95	42	
3 x 3	0.90	60	14 x 3	5 x 12	8.25	42	
2 x 4	1.22	60	15 x 3	6 x 12	11.90	42	
2½ x 4	1.28	60	15 x 3	7 x 12	16.28	42	
3 x 4	1.52	55	15 x 3	8 x 12	23.93	40	
3½ x 4	2.40	55	15 x 3½	9 x 12	28.22	40	
4 x 4	3.15	55	18 x 3½	10 x 12	34.60	40	
3½ x 6	4.30	55	20 x 3	12 x 12	49.30	40	
4 x 6	4.65	55	20 x 4½	14 x 12	69.22	40	
4½ x 6	5.10	55	20 x 4½	4½ x 16	8.00	35	
5 x 6	6.75	55	22 x 5	5 x 16	10.00	35	
5½ x 6	7.10	55	24 x 5	6 x 16	14.35	35	
4 x 8	7.80	55	26 x 5	7 x 16	19.60	35	
5 x 8	8.30	50	28 x 5	8 x 16	25.50	35	
6 x 8	11.10	50	30 x 6	9 x 16	32.20	35	
7 x 8	16.00	50	30 x 8	10 x 16	39.88	35	
8 x 8	17.00	50	36 x 4	11 x 16	48.30	35	
6 x 10	18.20	50	36 x 4	12 x 16	57.40	35	
7 x 10	19.50	50	36 x 6	13 x 16	67.20	35	
8 x 10	21.00	45	36 x 6	14 x 16	78.30	35	
9 x 10	30.00	45	42 x 8				

turning effort required on the shaft may be as uniform as possible and the flow of water steady. A type often used is single-acting with trunk plungers, *i.e.*, the connecting rod which drives the plunger is fastened to a pin inside the hollow body of the plunger, Fig. 47. This gives a compact form and one not likely to get out of order, but the trunk arrangement is inconvenient in case of any wear on the pin inside the plunger, and the side thrust of the connecting rod creates a certain tendency to wear the plunger packing so that it will not remain tight. On the whole it is better, though more expensive, to have a regular crosshead and ways to receive the thrust of the connecting rod, Fig. 51. The cylinders in this type of pump are usually vertical and the crank shaft is driven through a pair of reducing gears from a second shaft which, in turn, is driven by a pulley and belt or an electric motor. Table XIV gives some useful data regarding triplex pumps.

Direct-Acting Pumps. The most common type of direct-acting pump is steam-driven with steam piston and water piston, or plunger, on opposite ends of the same rod. For small sizes, the steam cylinder works without expansion of steam, the piston being driven by full boiler pressure throughout the stroke. In fact, it is impossible to avoid this feature of full-stroke admission, since the pressure in the water end is constant throughout the stroke, unless some means, such as a flywheel or accumulator, be provided, a complication which is undesirable with small powers. The simplest way to make any use of the expansive force of the steam is by compounding; *i.e.*, letting the steam exhaust from the small high-pressure cylinder, into which it is first admitted, to a larger low-pressure cylinder placed in tandem with the first one, Fig. 48. This arrangement gives a pressure on the low-pressure piston, which gradually decreases from the beginning to the end of the stroke while the pressure on the high-pressure piston is constant, so that whatever useful work is gained from expansion is in the

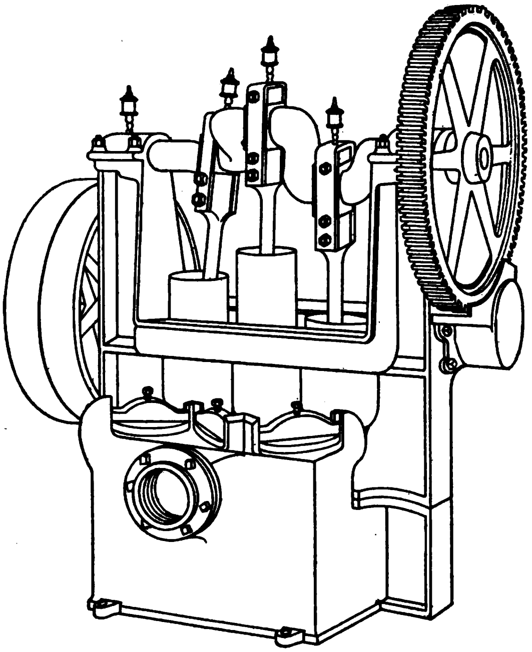


Fig. 47. Single-Acting Triplex Pump

low-pressure cylinder. However, in sizes having a water cylinder over 8×12 inches, this is found to be sufficient to pay for the extra cost if the service is continuous. The compound pump is nearly always duplex, though a few manufacturers offer a single tandem-compound style. Since the steam pistons must move together, the steam valves must move together, and a single motion serves to operate the valves for both high- and low-pressure cylinders.

The simple steam-driven pump requires from 60 to 120 pounds of steam per horse-power per hour; the gain by compounding is about 30 per cent per 100 pounds increase in boiler pressure, so that the steam consumption will be 40 to 95 pounds per horse-power per hour. The volume of the low-pressure cylinder is made from 2 to 4 times that of the high-pressure, depending on the initial pressure to be used.

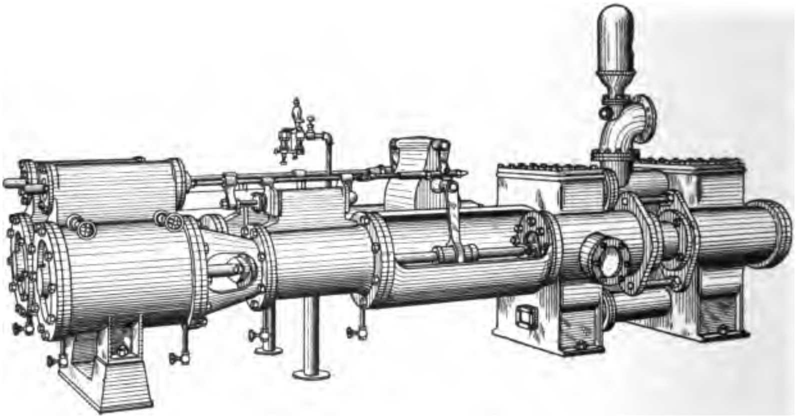


Fig. 48. Steam-Driven, Direct-Acting Pump

The large steam consumption of direct-acting pumps of the single-cylinder type has led to the adoption, in many large stations, of power-driven pumps of various kinds. It is probably true that the cost for steam is less by this method when the power is developed by large engines, even after the losses in transmission are accounted for, because the efficiency of the engine is so much greater than that of a small pump. But, for small plants, the convenience of having the pump located near its work and of being able readily to control the speed has overbalanced the consideration of saving.

Turbine-Driven Pumps. With the development of small steam turbines, a combination of a steam turbine direct-driving a centrifugal pump has come into use and is found very satisfactory. The most economical arrangement, considering first cost and depreciation, is a high-speed turbine and pump having large capacity for small weight. While the steam economy is not so good as in slower speed units, this disadvantage is usually offset by the fact that exhaust steam from the turbine is used for heating water about the plant. Besides, the higher speed unit will have a greater range of variation of speed at reasonable efficiency than the slower speed, hence will more readily meet the needs of auxiliary-unit conditions, which call for variation of the amount of water handled. An example of such a unit adapted for boiler feeding is shown in Fig. 49.

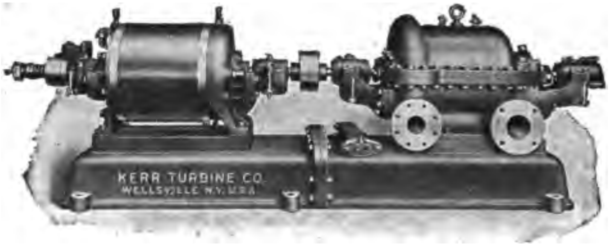


Fig. 49. Economy Turbo-Pump Designed for Boiler Feeding

Belt-Driven Pumps. As previously mentioned, nearly all power pumps are geared, the power being applied to a driving shaft, Fig. 47. The belted type is driven from a countershaft and provided with fast and loose pulleys used for starting and stopping, but there is usually no means of speed regulation. This, together with the expense of belting, the room needed, and the fact that the convenient location for a pump is likely to be such as to make a belt a nuisance, have prevented a general use of this type; and with the general introduction of electric power into all plants, the motor-driven pump is superseding it.

Motor-Driven Pumps. The motor-driven pump is of the same general form as the belted but has the electric motor mounted on the driving shaft, in place of the pulley, or connected by a double-reduction gearing, Fig. 50. The high speeds at which motors run make this double reduction necessary except in the case of large pumps. The only alternatives are the use of a large slow-speed motor or a belted motor, either of which would be cumbersome and expensive. As to efficiency, there is probably not much difference between the belted and the motor-driven types, as the economy of the electric method of transmission over that of the belted type will be offset by the losses in the motor and the extra set of gears. The speed of the motor may, however, be controlled by a starting box, or rheostat, in the field circuit; hence, the motor-driven pump has a considerable advantage over the belted type.

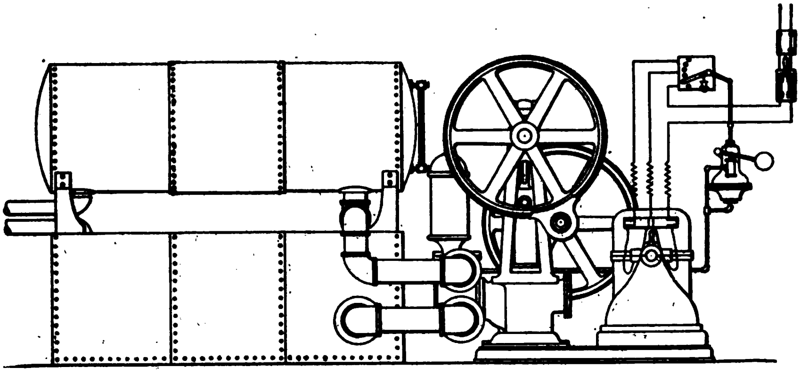


Fig. 50. Motor-Driven Pump with Double-Reduction Gearing

As compared with the direct-acting type the economy would be about thus:

Direct-acting—steam consumption, average, 90 pounds per hour per h.p.

Belt-driven—steam consumption of engine, per b.h.p. hour, average 35 pounds; at an efficiency of transmission for belting of 70 per cent and for gearing of 85 per cent this would require about 59 pounds of steam per hour per h.p. delivered to the pump, and at an efficiency of 75 per cent for the pump this would give about 78 pounds of steam per hour per h.p. of effective work.

Motor-driven—steam consumption as before, 35 pounds; efficiency of dynamo 93 per cent, of transmission 90 per cent, of motor 93 per cent, of gearing 72 per cent, of pumps 75 per cent, gives a steam consumption per effective h.p. of 83 pounds per hour.

With large units the efficiencies may be better, but the relation would be about the same. The greater convenience of the direct-acting pump as to size and means of control, and the ability to start it when the engine is not running, have weighed in its favor in the majority of cases.

For some few places, a gas or oil engine has been used for pump driving. In this type a clutch must be introduced between the engine and the pump, Fig. 51, as the engine will not start under load. The engine must first be started, then the pump thrown on empty, and finally the valves operated so that the pump will begin to work. There is no means of varying the speed, but a regulator is sometimes introduced which throws out the clutch when the water reaches a certain height in the tank or reservoir to be filled. This type is used only to supply water for a house or reservoir system.

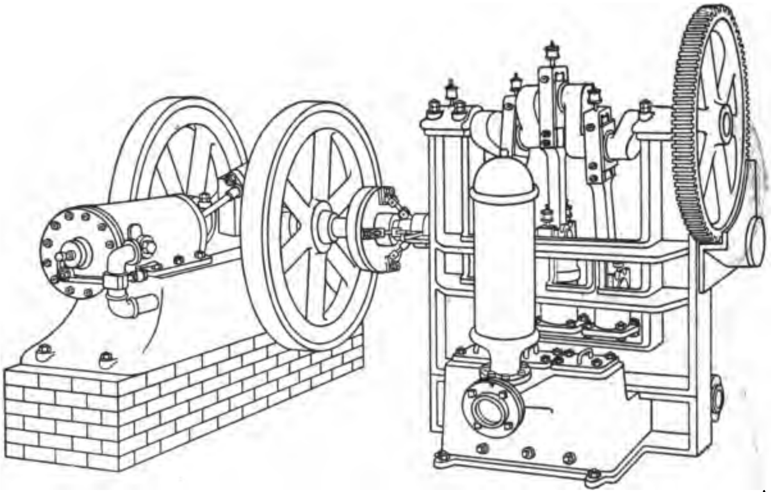


Fig. 51. Triplex Pump Driven by Gas Engine through Friction Clutch

To economize in floor space, the vertical marine type of pump is used. This is generally duplex, but occasionally single, and except for the vertical arrangement is identical with the horizontal type.

Combined-Condenser Pumps. Another special type is the combined-condenser pump, Fig. 52, in which the steam cylinder is placed in the center and drives on one end of the piston rod a vacuum pump for drawing the condensed steam and air from the condenser, and on the other end a pump for forcing the cooling water through the condenser tubes. The steam cylinder is the same as for any single pump except that there is a stuffing-box at each end; the water end is the same as for any pump; but the air-pump end has composition disk valves with an area of opening larger than that for a water cylinder of the same size, and the springs which close the valves are set at a less tension than for water.

Air pumps of special forms for condensers are often used combined with the condensers; they are driven by a separate engine or by a bell-crank lever from the crosshead of the main engine. The cylinders are often vertical and single-acting and work on the lifting principle with valves in the top of the bucket. A unique and in some ways commendable type is shown in Fig. 53, which avoids inlet valves and valves in the bucket yet removes both air and the water of condensation quickly and effectively. Condensed steam and air flow into the lower recess *A* through the passage *B* from the condenser; as the piston descends, it forces the water from *A* so that it shoots up in the direction indicated by the dotted lines through the ports *PP* into the cylinder *C*. The piston rising, closes ports *PP* and catches the water and air in the cylinder forcing them out through the valve *V* into the

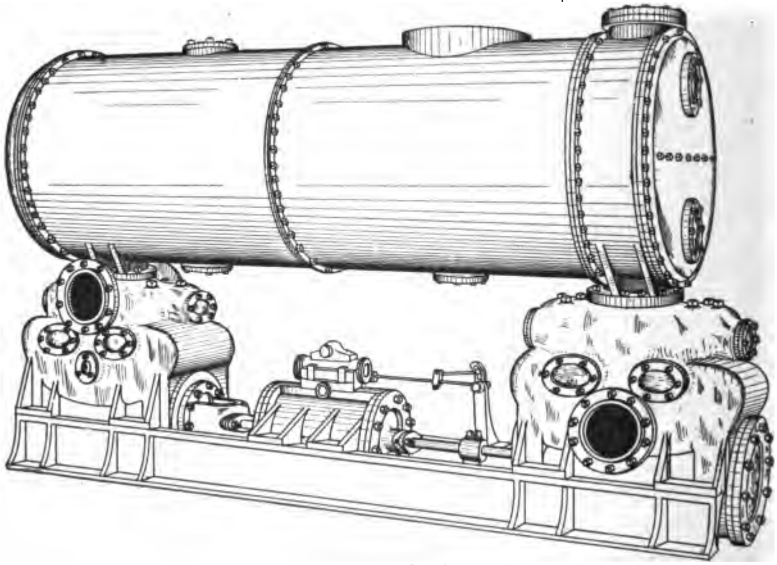


Fig. 52. Combined-Condenser Pump

discharge chamber *D*, whence the mixture escapes through the exhaust passage *K* to the hot well, or wherever may be desired.

Dry-Vacuum Pumps. For steam turbine plants it is desirable to maintain in the condenser a vacuum of 28.5 to 29.5 inches, and this necessitates that the air and gases be removed from the top of the condenser, as otherwise these gases collecting in large volume will expand and fill a considerable part of the condenser, reducing the condensing surface and interfering with satisfactory operation.

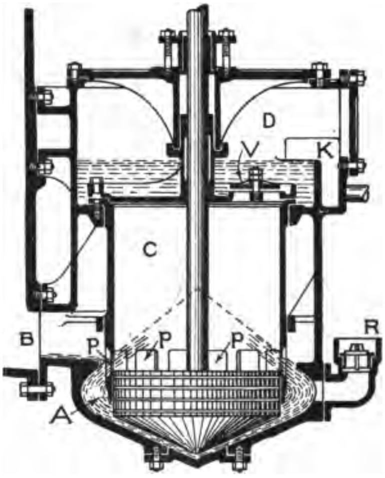


Fig. 53. Vertical Air and Condenser Pump

Pumps for this purpose are practically air compressors working at low pressure and are usually of the single-stage reciprocating type. Clearance is made as small as possible; water-sealed valves are frequently used, with the suction placed below the bore of the cylinder. The suction valve is frequently of the positively-driven Corliss or slide-valve type, and a poppet discharge valve is used in addition.

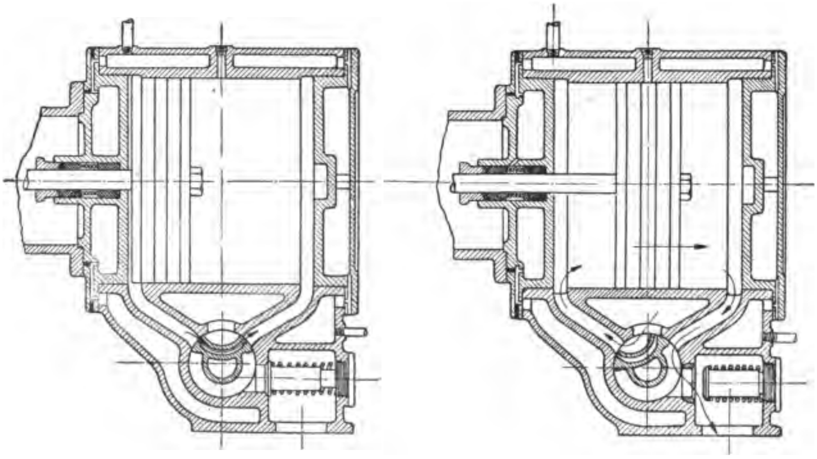


Fig. 54. Oscillating-Valve for Dry-Vacuum Pump

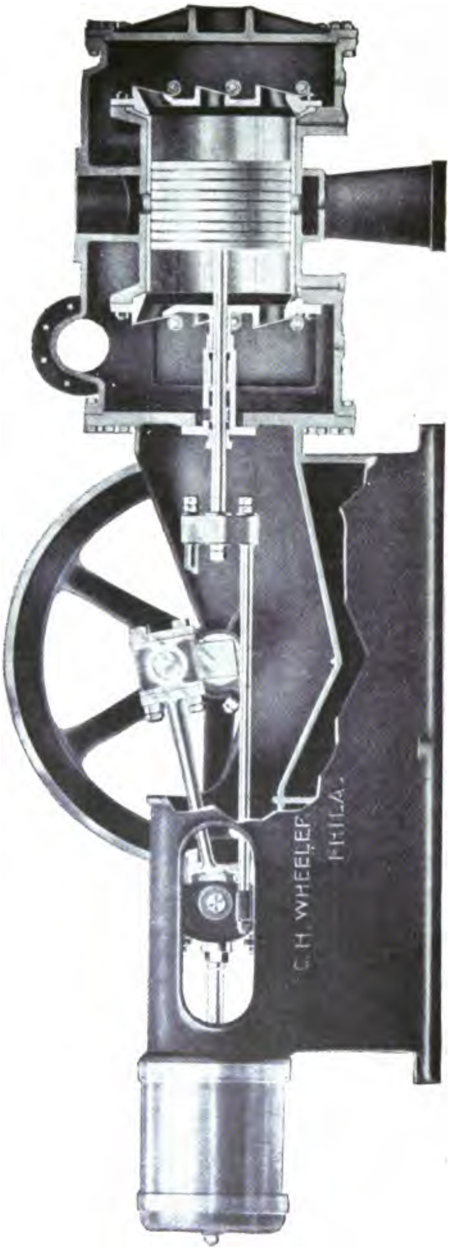


Fig. 55. Mullan Valveless Dry-Vacuum Pump
Courtesy of C. H. Wheeler & Company, Philadelphia, Pennsylvania

The construction and action of such a pump cylinder are shown in the two sectional views given in Fig. 54.

In the left-hand view, the oscillating valve is in central position on the point of opening the left end of the cylinder for inlet and the right end for discharge. The flash port through the valve, which temporarily connects the two ends of the cylinder, is to release the compression pressure at the left end so as to avoid re-expansion of the gas during the suction stroke, which would reduce the capacity of the pump. There is no connection to the discharge opening, so that no air can back up from discharge into the pump cylinder. The poppet valve at the right of the oscillating valve is closed.

As the pump moves, the oscillating valve is turned to the position shown in the right-hand view. Air is drawn into the left end of the cylinder, as shown by the arrow, and compressed in the right end until the pressure is sufficient to force open the poppet valve, which is held closed by a spring. Air and gases are then forced out into the atmosphere from the right end of the cylinder until the end of the stroke, when the oscillating valve is reversed and the right end becomes the suction end and the left end compresses.

Another type of dry-vacuum pump is shown in Fig. 55. The piston operates to create a vacuum until near the end of its travel, when it uncovers a series of ports located in a belt around the middle of the cylinder. Vapor and air are drawn through these ports, filling the cylinder, no valves being used. On the return stroke, the gases are compressed until they open the Gutermuth valves, of flexible metallic type, located in the cylinder head and then are discharged into the atmosphere. Each of these valves consists of an elastic plate of phosphor bronze coiled at one end and held in a flattened valve stem which is bolted to the valve deck. The other end of the plate is flat to serve as a flap valve. The stem can be turned to give any desired tension on the coiled end and thus control the discharge pressure.

Compressed-Air Pumps. Pumping water by compressed air was known early in the nineteenth century, but nothing practical resulted until Dr. J. G. Pohlé took up the matter in the early seventies.

The principle of operation is shown in Fig. 56. A discharge pipe is let down into the well so that its lower end is deep below the surface. Compressed air is forced down through a smaller air pipe and is liberated inside the lower end of the discharge pipe at a high pressure.

The air mixes with the water, producing a column that is lighter than water alone, and this column, owing to its decreased specific gravity, will rise until the pressure at the lower end of the pipe, due to the water outside, is equaled by that due to the mixture inside. Air must be introduced continuously, as it readily separates from the water. The proportions of submergence and lift must be such that the lighter column of mixture will rise to a point where it can discharge into a receptacle at the desired level.

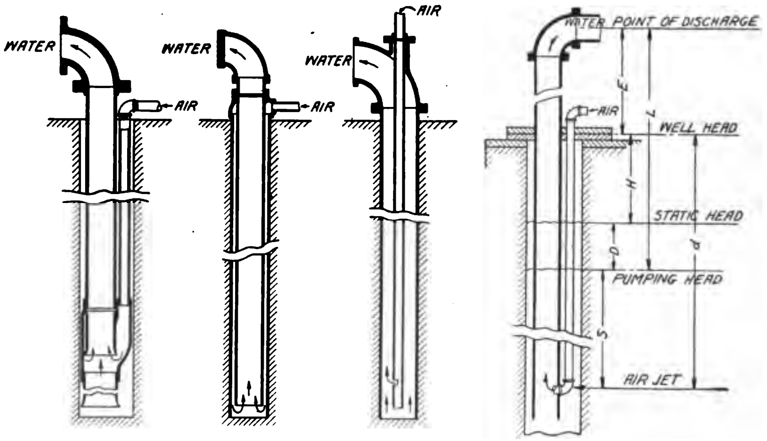


Fig. 56. Various Arrangements of Air Piping for Air-Lift Pumps

Four arrangements of air and water pipe are shown in Fig. 56. To get a clear idea of the system and the proper proportions, certain terms to be used must be definitely understood. Referring to the right-hand portion of Fig. 56, the static head *H* is the distance from ground level to the standing level of water in the well when not pumping. Drop *D* is the distance the water recedes from its static level when the well is delivering water. Lift *L* is the static head plus the drop plus elevation *E* of the delivery outlet above ground level. Submergence is the distance the end of the air pipe is submerged below water level and has two values—starting submergence, which is temporary, and running submergence S, which is the important factor in an air-lift pump proposition. Submergence is expressed either in feet, or as a percentage of the total depth from the point of discharge to the lower end of the air pipe; it varies from 66 per cent for lifts of 20 feet to 41 per cent for lifts of 500 feet. Depth d is the distance of the foot piece or air outlet below ground level.

Pressure. The pressure of air P_s required at the start is larger than that needed for running. It is used in overcoming the head of water in the discharge pipe and can be found by use of the following equation:

$$P_s = (d - H)0.434$$

The working pressure P_w is that required for steady operation and is less than the starting pressure. It can be determined from the following equations:

$$P_w = 0.434 \times S + \text{pressure loss due to friction in pipe} + 2 \text{ lb. for back pressure in the pump}$$

or

$$P_w = (d - H - D)0.434 + \text{friction pressure loss} + 2$$

Knowing the lift and running submergence, the volume V of free air needed per gallon of water handled can be found from the equation

$$V = \frac{L}{\log\ [(S+34) \div 34]\ C}$$

in which C is a constant varying with the lift as given in Table XV, which also includes values worked out from the foregoing formulas for various conditions.

Efficiency. The efficiency increases as the ratio of running submergence increases. There is much disagreement as to the efficiencies that can be obtained, but the amounts which may reasonably be expected, as indicated by certain tests, range from 18 per cent (for a ratio of submergence of 43 per cent) up to 37 per cent (for a ratio of 72 per cent), the efficiency being based on the power required to compress the air.

A great deal depends on the proper proportioning of the size of air pipe to discharge pipe, and on submergence of the air pipe.

TABLE XV

Constants for Air-Lift Pumps, Giving Free Air Required at Various Ratios of Submergence

For values of L in feet of	(10-60)	(61-200)	(201-500)	(501-650)	(651-750)
The values of C are	245	233	216	185	156

$\frac{S}{S+L}$	25%		33%		43%		50%		55%		60%		66%		70%		75%	
$\frac{S}{L}$	⅓ to 1		½ to 1		¾ to 1		1 to 1		1¼ to 1		1½ to 1		2 to 1		2⅓ to 1		3 to 1	
Lift (feet)	Free Air	Working Pres.	Free Air	Working Pres.	Free Air	Working Pres.	Free Air	Working Pres.	Free Air	Working Pres.	Free Air	Working Pres.	Free Air	Working Pres.	Free Air	Working Pres.	Free Air	Working Pres.
20							.408	9	.349	11	.296	13½	.241	18	.207	22½	.186	27
30							.449	13½	.382	17	.334	20	.277	27	.243	34	.220	40½
40							.475	18	.416	22½	.369	27	.311	36	.274	45	.251	54
50							.522	22½	.449	28	.403	34	.344	45	.306	56	.272	67½
60							.556	27	.487	34	.436	40½	.374	54	.335	67½	.308	81
80							.657	36	.573	45	.525	54	.458	72	.412	90	.382	108
100					.855	34	.724	45	.643	56	.588	67½	.515	90	.468	112½	.435	135
120					.92	40½	.79	54	.707	67½	.646	81	.570	108	.523	135	.486	162
140					.988	47	.852	63	.768	79	.701	94½	.626	126	.575	157½	.536	189
160					1.05	54	.913	72	.825	90	.76	108	.679	144	.628	180	.586	216
180					1.113	61	.971	81	.88	101	.815	121½	.73	162	.676	202	.634	243
200	1.81	30	1.442	45	1.172	67½	1.028	90	.935	112½	.867	135	.78	180	.724	225	.678	270
250	2.12	38	1.725	56	1.42	84	1.25	112½	1.155	141	1.069	168	.97	225	.898	282		
300	2.295	45	1.895	67½	1.63	100	1.4	135	1.305	169	1.14	200	1.093	270	1.02	338		
350	2.47	53	2.05	79	1.77	118	1.569	157½	1.425	197	1.335	236	1.200	315	1.135	394		
400	2.65	60	2.22	90	1.87	135	1.67	180	1.615	225	1.455	270	1.333	360	1.25	450		
450	2.82	68	2.37	100	2.00	152	1.805	205	1.67	253	1.578	304	1.445	410	1.385	506		
500	2.97	75	2.52	112½	2.115	169	1.94	225	1.792	281	1.700	338	1.56	450	1.467	562		
550	3.65	83	3.11	128	2.665	185½	2.41	247½	2.24	309	2.12	371	1.98	495				
600	3.82	90	3.25	135	2.81	205	2.55	270	2.385	337½	2.255	410	2.08	540				
650	4.00	98	3.45	146	2.97	219	2.75	292½	2.545	365½	2.41	438	2.205	585				
700	4.97	105	4.27	157½	3.69	236	3.38	315	3.15	394	3.00	472	2.765	630				
750	5.18	113	4.46	169	3.86	256	3.53	337½	3.34	424	3.12	512	2.900	675				
800	5.40	120	4.64	180	4.03	270	3.70	360	3.48	450	3.29	540	3.100	720				
850	5.58	128	4.82	191	4.20	287	3.86	382½	3.62	478	3.44	574	3.19	765				
900	5.78	135	5.00	202½	4.37	304	4.01	405	3.75	506	3.49	608	3.33	810				
950	5.97	143	5.18	214	4.50	322	4.17	427½	3.92	535	3.73	644	3.47	854				
1000	6.17	150	5.36	225	5.19	337½	4.33	450	4.07	562½	3.87	675	3.62	900				

TABLE XVI

Well Pipe Sizes for Air-Lift Pumps

Well Casing (in.)	Side Inlet			Center Air Pipe	
	Water Pipe	Air Pipe	Capacity (g.p.m.)	Air Pipe	Capacity (g.p.m.)
3½	. .	. .	. .	1¼	115
4	1½	¾	25	1½	150
4½	2	1	50	. .	. . .
5	2½	1	75	2	240
6	3	1¼	105	2	360
7	3½	1½	145	. .	. . .
8	4	1½	190	. .	. . .
9	5	2	300	. .	. . .
10	6	2	425	. .	. . .

The approximate sizes for well pipe, as given by C. M. Wetherell, are given in Table XVI.

In arranging the inlet of air to the water pipe, the object is to secure a mixture of air and water that is as intimate as possible and resembles foam. In the first arrangement, Fig. 56, air enters all around the periphery of an annular space about the Pohlé foot piece. Where a side air line cannot be used, the second, or Saunders, arrangement may be used, air being sent down between the water pipe and casing. The action is the same as before. The third arrangement shown is the central air-pipe system, which obtains the greatest possible output for a given size of casing. The whole casing becomes the water pipe.

If the air pipe is too large, more air will be furnished than is needed and the discharge velocity will be too great; if the air pipe is too small, the air supply will not be sufficient to get full capacity from the casing. A velocity in the air pipe not exceeding 20 feet per second is recommended.

Air-Lift System. The following machinery is necessary for an air-lift system: An air compressor of size sufficient to give the needed air supply; a reservoir large enough to break up the pulsations from the compressor and to steady the flow; gauges and valves for regulating the pressure; and the necessary well piping.

For pressures up to 60 pounds, a single-stage duplex compressor will answer; for pressures between 60 and 300 pounds, a two-stage compressor, with an inter-cooler between cylinders, will be found economical; while for pressures above 300 pounds, a three-stage compressor should be used.

A typical arrangement for an air-lift plant is shown in Fig. 57, one well only being shown, although any number may be handled from a single compressor. In laying out a plant, the location of the wells, compressor, and piping should be so chosen as to involve as few bends and valves as possible, and generous-sized piping should be used to reduce friction losses.

When the distance from the compressor to the well or wells is short, it is sometimes of advantage to inclose the discharge pit and pipe the air, which separates from the water and is at a considerable pressure above atmosphere, back to the compressor. This air is at a comparatively low temperature, hence will require less power to compress and cause less heating in the compressor than air taken direct from the atmosphere. Care must be taken, however, that no water is carried over to the compressor with this air.

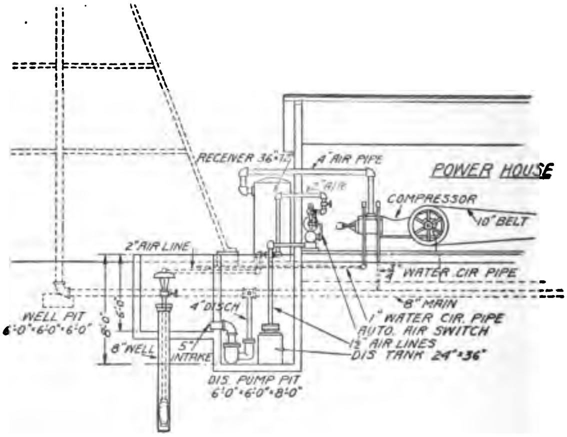


Fig. 57. Diagram of Air-Lift Pumping Plant

Horse-power required for compressing air, per cubic foot of free air handled per minute, varies from 0.036 for 10-pound pressure up to 0.134 for 60-pound single stage; and from 0.131 for 80-pound pressure up to 0.217 for 200-pound double stage.

Boosting. If it is desired to raise water much above ground level or to force it a long distance horizontally, air boosting is used. The air is separated from the water in a closed discharge chamber at the top of the well and its pressure is utilized to force the water to the desired point, as indicated in Fig. 58. The work to be done by the booster should not be over 25 per cent of the total work of the plant. Air is released from the booster head by an automatic valve arranged so as to hold the water level about constant.

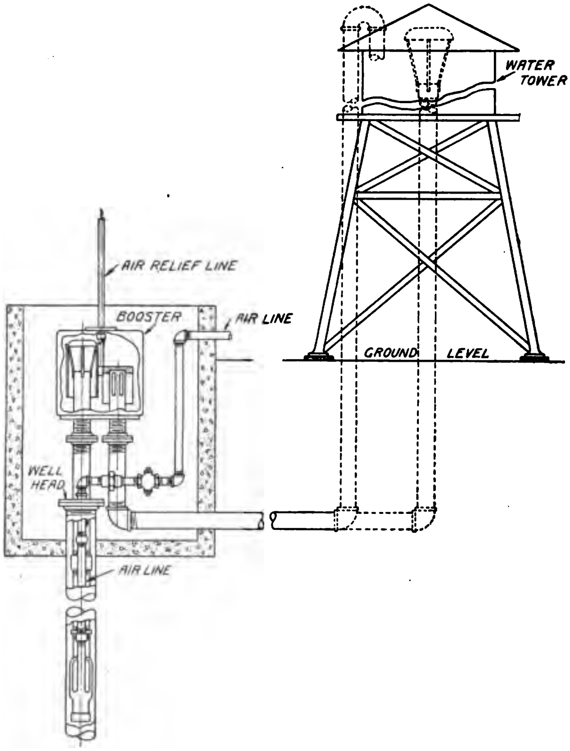


Fig. 58. Air-Lift Pump and Booster System

Characteristics of System. The advantages of the air-lift system are: its simplicity; its concentration of all machinery into one place which can be conveniently located; and its ability to handle water containing grit, stones, or ashes without injury to the machinery. However, the efficiency is low and a great depth of well in proportion to the lift is needed. The air-lift system is not adapted to all classes of service, but for handling a number of scattered wells, or a single deep well in an awkward location, it is simple and effective.

AUTOMATIC CONTROL

For certain uses, such as keeping up the pressure on a hydraulic elevator system, draining a pit, or maintaining the water level in a tank, it is essential to have an automatic method of control which shall start and stop the pump as may be needed. For direct-driven steam pumps, this is accomplished by control of a damper valve or a quick-acting gate placed in the steam pipe, and actuated by a float which is moved with the change in water level. For the motor-driven pump, the action is by means of a switch on the starting-resistance box; the diaphragm which is worked by the tank pressures, actuating a series of levers, Fig. 50, so as to work the steam valve or switch as the case may be.

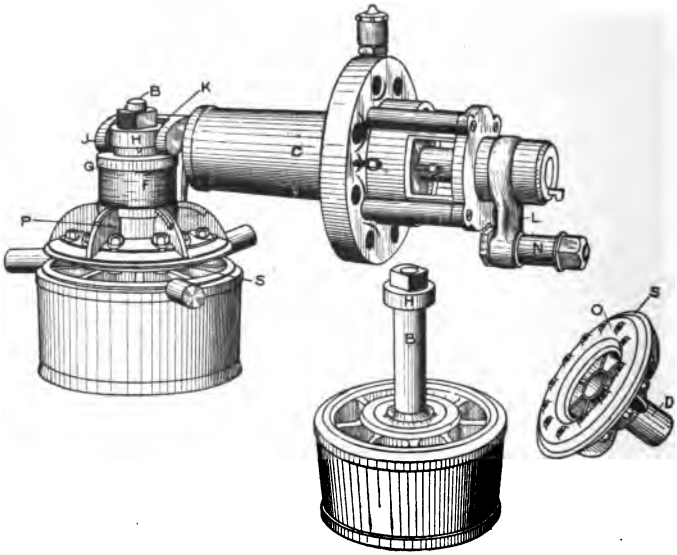


Fig. 59. Riedler Mechanically Operated Valves.

For high pressures and high speeds what is known as the *Riedler System of mechanically operated valves*, Fig. 59, is found especially desirable. The valve is of the poppet type, made so large that one valve answers for each end of a cylinder and is opened and closed

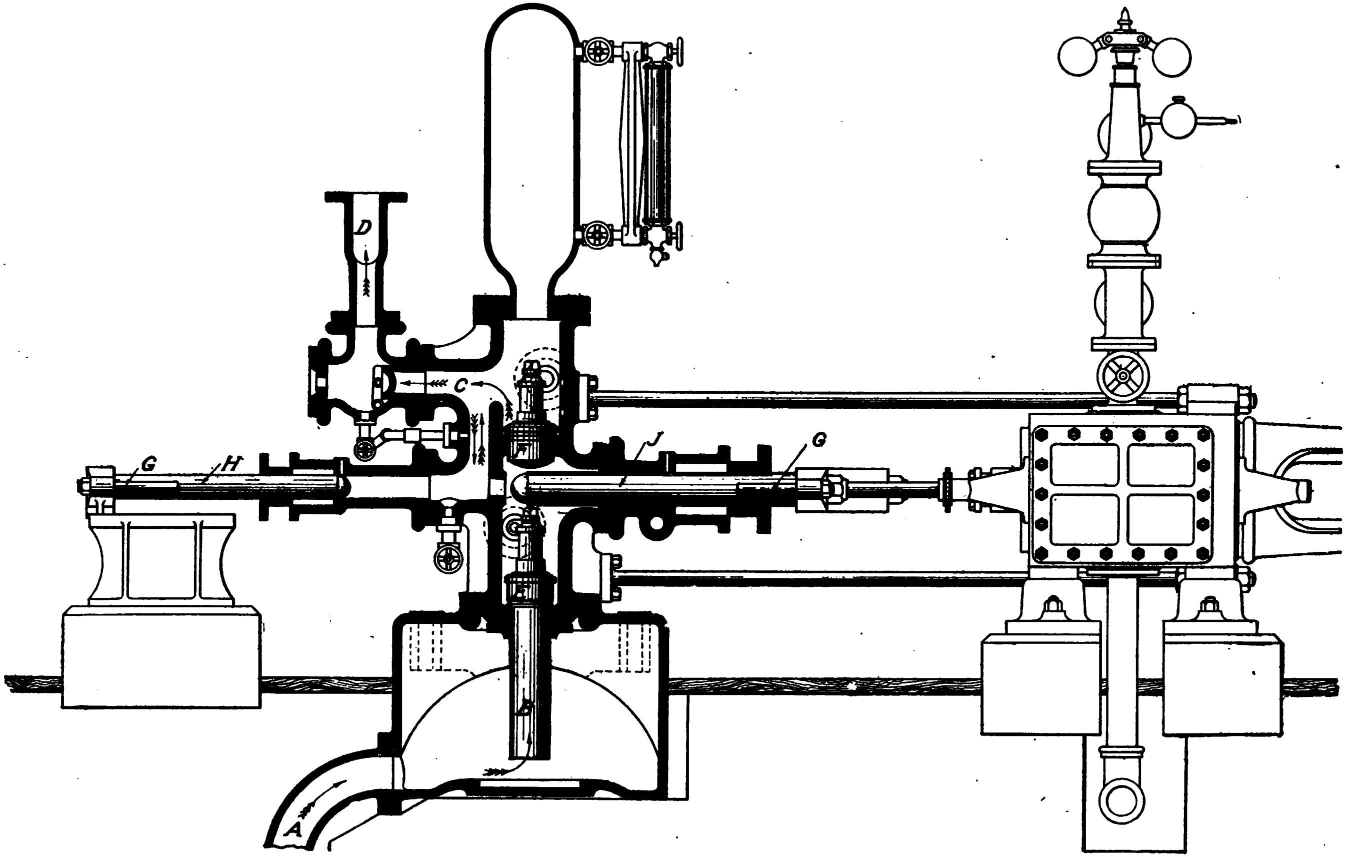


Fig. 60. Differential Pump for High Pressures.

by a rocking arm *N*, turned by a link and driven from a wrist-plate much as in a Corliss-engine valve motion. The mechanical driving permits a high lift, with rapid opening and closing at the end of the stroke, thus decreasing the slip and shock. The high lift, 1 to 2 inches, and large water passages decrease the friction while the mechanical operation of the valves also allows of the high piston speed necessary to secure economy in steam consumption.

Referring to Fig. 59, the valve body *P* has on its lower face a leather seal *S* secured by a plate *O*. The sleeve *D* works on the spindle *B*, raised by a pin in the arms *K* which passes under the collar *H* and is lowered by the pressure of the blocks *J* on the cushion plate *G*. *F* is a rubber buffer to take the shock in case an obstruction gets into the valve. The arms *K* are mounted on and turned by a spindle which passes through the bushing *C* and is rotated by the crank *L* and crank pin *N*. One valve is used for inlet and one for outlet on each cylinder, as seen in the right-hand plunger, Fig. 60; for the left-hand end, the outlet valve of the larger plunger acts as an inlet, and the clack valve between the passages *C* and *D* acts as an outlet valve. This type of pump, known as the *differential* pump is used for high pressures and to give a continuous flow with few valves; the cross-section of plunger *H*, Fig. 60, is half that of *J*, hence, on the stroke towards the left, half the water discharged by *J* is thrown into the small plunger chamber and half into the passage *D;* on the stroke towards the right, the half which entered the small plunger chamber is driven into chamber *D*, and the large plunger draws its full quantity through the suction pipe *B*. The large passages and valves, the ample discharge and suction air-chambers, together with the positive opening of the valves, combine to make this pump very efficient and quiet in running. However, it requires a large space in proportion to its capacity while its complexity makes it expensive, so that it is available only for large sizes and in places where the space occupied is not of special importance.

STEAM VALVES

D-Valve. The D-valve, the simplest form of valve, is used with a fly-wheel pump and is moved by an eccentric, Fig. 45; the detail is shown in Fig. 61, and the action is as follows:

With the valve *v* in the position shown, steam is flowing through the port *a′* into the right-hand end of the cylinder and forcing the piston towards the left; at the same time, any steam which may be in the left-hand end of the cylinder is driven out through the port *a* into the exhaust passage *b* and thence to the exhaust pipe. If the shaft *M* be turning as indicated by the arrow, the eccentric *e* which is keyed to it, will also turn, and, sliding in the eccentric strap *S*, will draw it towards the right, thus operating the valve. When the eccentric has made a fourth of a revolution it will be vertically above the shaft, and will have drawn the valve over so that it covers both ports, while, at the same time, the piston will have moved so that it will stand at its extreme left-hand position. As the motion continues, the left-hand port *a* will be opened to steam, and the port *a′*, to exhaust, causing the piston to reverse and move towards the right, which will continue until the eccentric has moved the valve to its extreme right-hand position and back to cover both ports. The eccentric standing directly below the shaft, the piston will again reverse and start towards the left, and the cycle be repeated.

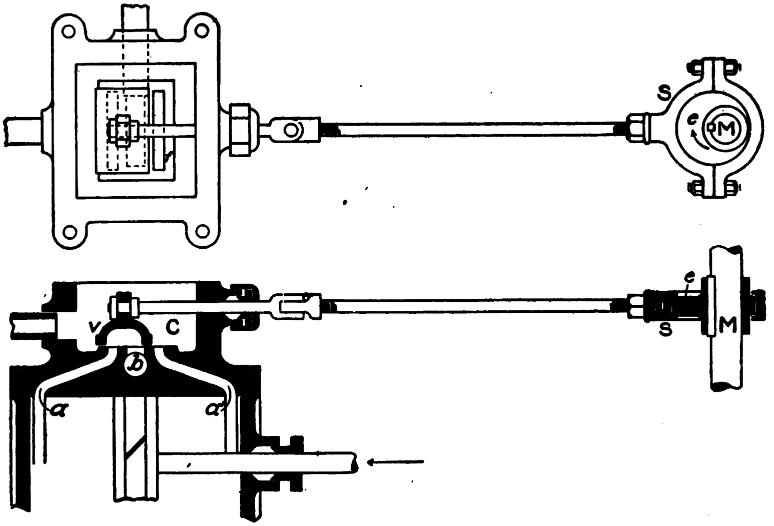


Fig. 61. Steam Valve—D-Form

For the ordinary pump the valve is made so that when in mid position it just covers the ports, and steam will enter one or the other end of the cylinder, if the valve is moved from that position. Steam will then be admitted full stroke and work without expansion in the cylinder. If it is desired to utilize some part of the expansive force of the steam, a *lap* must be added to the valve as shown at *a*, Fig. 62, so that the port may be closed before the piston reaches the end of the stroke; then the eccentric must be turned forward on the shaft in the direction of its motion in order that the valve may open by the time the piston is ready to reverse, and then *inside lap b* must be adjusted so that the exhaust port will neither open too soon; thus wasting steam energy, nor close too early, thus leaving too much steam between the piston and the end of the cylinder.

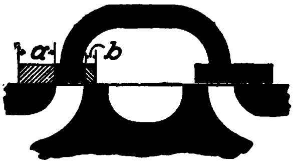


Fig. 62. D-Valve with Lap.

B-Valve. The action of this valve, Fig. 63, is the same as for the D-type, except that steam flows into the cylinder through the cup-shaped cavity in the valve instead of past the end, and that the motion of the valve relative to that of the piston is opposite to that for the D-valve. The B-type is adapted for use with the steam-driven valve to be described, but is not suited to be driven by an eccentric. The steam-driven valve is used on the great majority of small single pumps on account of its compactness, light weight, and low cost, and in spite of its poor steam economy. In a few of the first named pumps—for instance, the early Worthington, single type—the main steam valve was moved by tappets on the valve rod which were struck by an arm fastened to the piston rod. This was not reliable and the main valve is now operated by a small piston working in an auxiliary cylinder. Steam is admitted to this cylinder by an auxiliary valve moved by a tappet or lever mechanism which is worked from the main piston rod.

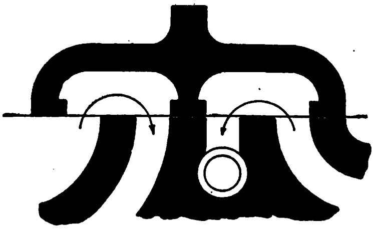


Fig. 63. B-Valve.

Designs of Different Makers. The first steam valve to be developed was the *Knowles*, Fig. 64. The chest piston *A* is moved by steam admitted through ports *m* and *z* between the end of the chest piston and its cylinder, and carries with it the main steam valve *B*, which opens and closes the ports to the main steam cylinder. The ports $x\ y\ z$ and $x'\ y'\ z'$, of the small detail view, are made to register with the ports $m\ n$ and $m'\ n'$ by the turning of the chest piston by the tappet *C* driven by the rocker-bar *R* and the roller *E*. As the main piston reaches its left-hand position, the roller *E* will lift the left-hand end of the rocker bar and place the ports so that steam is admitted to the right of the chest piston and is exhausted from the left; the main valve will then be carried to the position shown in Fig. 64 and steam will be admitted to the left-hand end of the main steam cylinder in order to drive the main piston towards the right. At the other end of the stroke the operation will be reversed. The arm *F* will not strike tappets *C* or *D* unless the steam fails to move the main valve, in which case the piston *A* would be driven by pressure on the tappets, but with more or less slamming, depending on the speed.

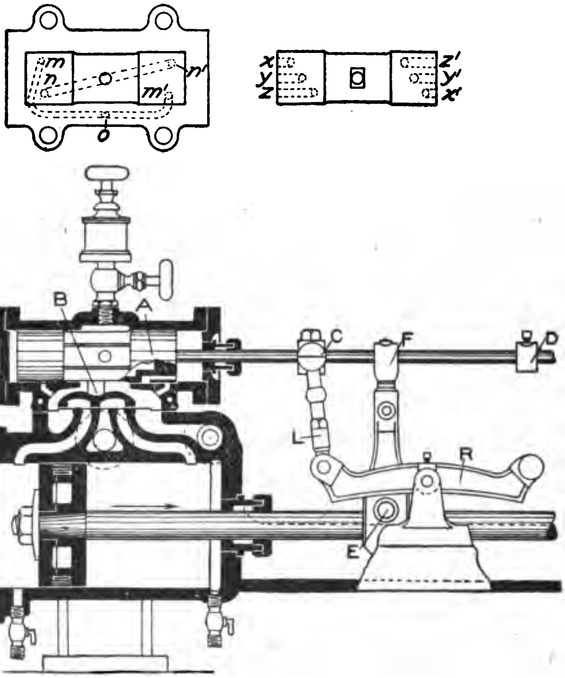


Fig. 64. Knowles Steam Valve.

The third set of ports in the chest piston and its seat are to form a connection between the two ends of the auxiliary cylinder after the chest piston has moved a certain distance in order to prevent its striking the end of the chest. The length of stroke can be changed by altering the height of the roller *E,* and unevenness of stroke at the ends can be remedied by changing the length of the link *L.*

An entirely different style of valve is that of the *Cameron* pump, Fig. 65. *F* is the valve piston which drives the valve *G* by means of a projection which sticks up through the neck of the piston. The ends of the valve piston are hollow, as shown in the cross-section of the right-hand end, and a small hole *P* at each end admits steam at full pressure to the ends of the chest cylinder. If the main piston *C* is moving to the left—as it would be with the valve *G* in the position shown—when it reaches the end of the stroke, it will strike the reversing valve *I′* and force it open, thus allowing the steam at the left of the valve piston to flow into the exhaust port through the passage *E′*. The steam at the right-hand end of the valve piston will expand, forcing the piston *F* to the left and carrying valve *G* with it, thus opening the right-hand end of the main cylinder *A* to the exhaust and the left-hand end to live steam, which will reverse the motion of the piston *C*. As the valve piston moves to the left,

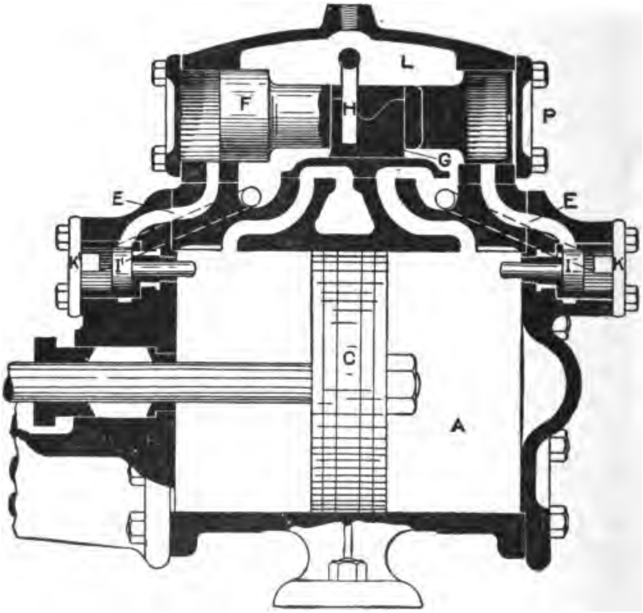


Fig. 65. Cameron Steam Valve.

it will cover and close the port *E'*, and hence will be brought to rest without shock by the cushioning effect of the enclosed steam. As soon as the piston *C* leaves it, the reversing valve *I'* will be closed by the pressure in the passage *K'* which is filled with live steam. At the other end of the stroke, the same series of operations follows by the action of the reversing valve *I*.

The valves require no adjustment and are easily brought to a new seat when they become worn, by removing the bonnets. If piston *F* becomes worn after long service, the cylinder may be rebored and bushed or the holes *P* may be drilled a little larger, which will give greater pressure in the end of the chest cylinder and keep the pump working steadily for a long time even with the piston *F* considerably worn. A starting lever *H*, worked by a handle outside, is for use in case the pump should stop with the valve *G* covering both admission ports.

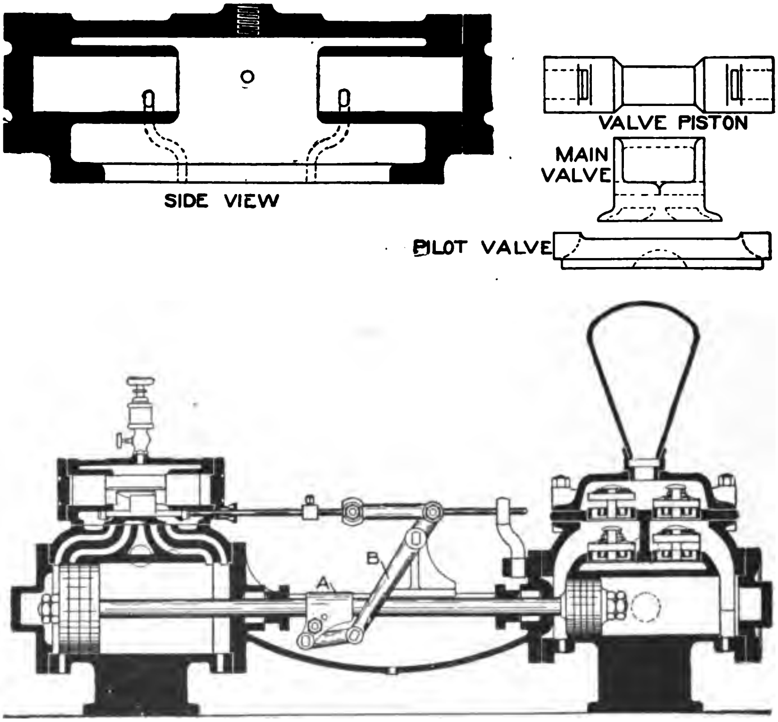


Fig. 66. Details of Deane of Holyoke Steam Valve.

A third style of valve, Fig. 66, is the *Deane of Holyoke.* In this the auxiliary valve is in the form of a yoke surrounding the main valve; the working-valve seat and ports for the auxiliary are at one side of the main valve seat, and the ports supply steam to, or exhaust it from, the end of the valve-piston chamber through openings in the end of the piston. The auxiliary valve is moved by a valve rod actuated by tappets and a series of levers from the main piston rod. If the valve piston fails to move the main valve, the auxiliary valve, acting as a yoke, will finally drive the main valve over, by positive action.

A somewhat similar device is used on the *Dean Brothers* pump, Fig. 67. There is, however, no period of rest of the auxiliary valve, the motion being similar to that given by an eccentric; and there is no provision for moving the main valve other than by the valve piston, because the positive driving of the auxiliary valve makes this unnecessary. The auxiliary valve *F* works on a seat *G* on the side of the valve-piston cylinder, being driven by the rod *A* and the rocker arm *R* from the main piston rod *P*. The length of its stroke can be

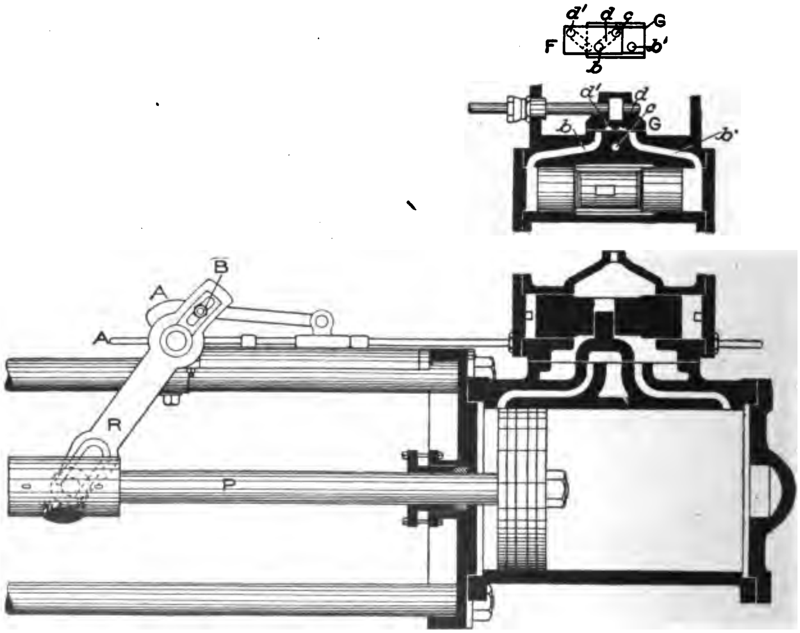


Fig. 67. Dean Brothers Steam Valve.

changed by moving the pin *B* in the slot of the rocker arm, and thus the stroke of the main piston will be changed. The main valve is of the D form with a projection from the top which is engaged by the valve piston; the ports enter the cylinder, as in practically all direct-driven, steam pumps, at some distance from the end; thus steam will be caught to form a cushion for the piston at the end of the stroke.

The auxiliary valve, Fig. 67, is made very short and is so arranged that its ports are open only when the main piston is near the end of its stroke. Ports *b b′* are for admission of live steam and port *c* is for exhaust. All three ports are covered by the valve except when near the end of its travel; then the groove *d* in the face of the valve connects ports *b* and *c* and allows the steam to exhaust from the left-hand end of the valve piston while port *b′* is uncovered and live steam is admitted to the right-hand end; or, at the opposite end of the stroke, groove *d′* connects *b′* and *c*, and *b* is uncovered. This construction prevents waste of steam if the valve piston becomes worn in its cylinder, since live steam is conducted to that cylinder only during the moment of moving the piston.

A valve with a peculiar cut-off action is used on the *Blake* pump, Fig. 68. Steam is entering the head end of the cylinder through the ports *E* and *H*, and is exhausting from the crank end through ports *H′*, *E′*, *K*, and *M*. As the main piston *A* nears the crank end of the stroke, the valve *C* is moved to the left by a system of levers similar to those on the Deane pump, which strike tappets on the rod *P*. When this happens the lug *S* on the valve *C* covers the auxiliary steam port *N*, and *S′* uncovers the auxiliary steam port *N′* (see plan view), while the auxiliary exhaust port *Z* is disconnected from *X′* and connected to *X*, thus allowing steam to exhaust from the piston chamber at *B′* and flow into that at *B*. The main valve *D* will be carried to the right by supplemental piston and will connect port *E* to *K*, leaving *E′* uncovered for the entrance of live steam, and the main piston will be forced towards the head end. It is not necessary to provide for positive mechanical driving of the main valve, as live steam can always enter one end or the other of both main and supplemental cylinders. The supplemental piston is fitted with rings so that it will take up its own wear, and prevent leakage into the exhaust, while the motion is such that the main valve has a slight lead on the main piston, thus admitting live steam to cushion the latter at the end of its stroke and to prevent slamming. Also, in case the main valve sticks, the valve *C* moves far enough to admit sufficient steam past the end of the main valve for the cushioning effect.

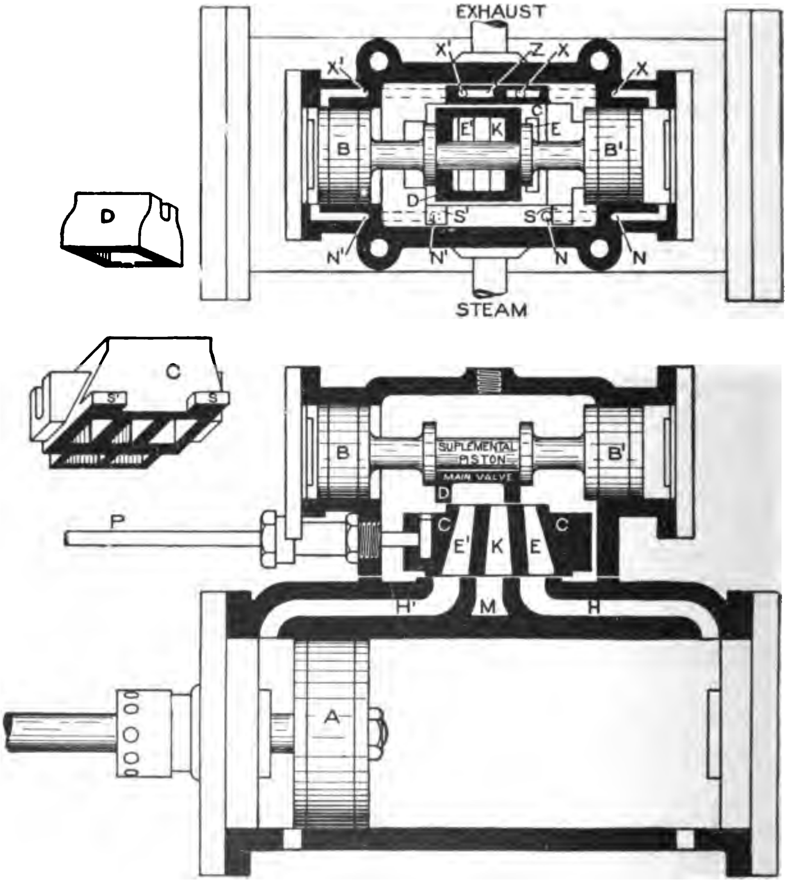


Fig. 68. Blake Pump Valve with Special Cut-Off.

The supplemental piston cushions on the steam caught as it passes by the end of the port *X* or *X'*.

The *Davidson* pump, Fig. 69, has but one valve, which is operated by an auxiliary piston. The admission of steam to the ends of this piston is accomplished by the oscillating motion of the main valve itself. This motion is caused by a pin turned by a cam and oscillating lever driven from the pump rod. In the position shown, steam is being admitted to the crank end and exhausted from the head end; consequently the piston is moving towards the right. As it nears the end of the stroke, the cam *C* will rotate the pin *D* and place valve *A* in position to connect the port *E′* with the exhaust chamber

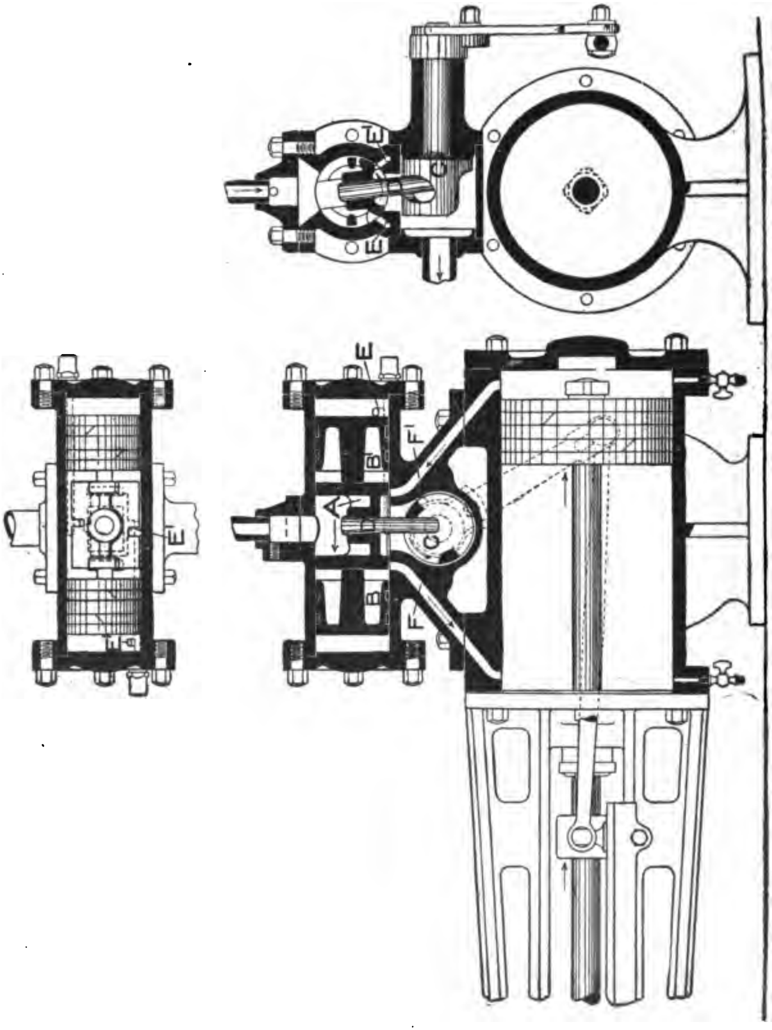


Fig. 69. Details of Davidson Pump Valve.

while opening *E* to live steam, as seen in the end view. The pin *D* will then be driven towards the left, carrying with it the valve *A*. Ports *E′* and *F* will be closed so that the main piston will be cushioned on the steam remaining in the cylinder.

The movement of valve *A* to this central position opens *E′* to exhaust and *E* to live steam, and the piston *B B′*, carrying with it valve *A*, is forced to the left, opening port *F* to exhaust and *F′* to live steam, and allowing the main piston to move towards the left. When valve *A* is in a position to cover both ports *F* and *F′*, either *E* is open to steam and *E′* to exhaust, or *vice versâ*, consequently the pump is always ready to start as soon as steam is turned on.

Various other forms of steam end have been used by different makers, but they work on practically the same principles as those described, being different only in details.

Duplex Pump Valves. The steam valve on one side of a duplex pump is moved by means of a valve rod and lever connected to the piston rod on the other side, so that one side starts when the other has reached about three-quarters stroke. The steam valves are usually of the D form, having separate ports for admission and exhaust at each end, Fig 70. Valve *B* is moved by rod *C* and bell-crank lever *D*, the hidden end of which is driven from the farther piston rod by a device like *H*, while the farther valve is driven by the rocker-arm lever *G F E*. The double ports are used so that the piston may run over the exhaust port and close it before reaching the end of the stroke, thus getting a steam cushion, and yet live steam may have a chance to enter behind the piston even if it stops quite at the end of its possible motion. In large sizes—particularly in fire pumps—a cushion valve is placed in a passage connecting the steam and exhaust ports, so that the amount of by-pass opening

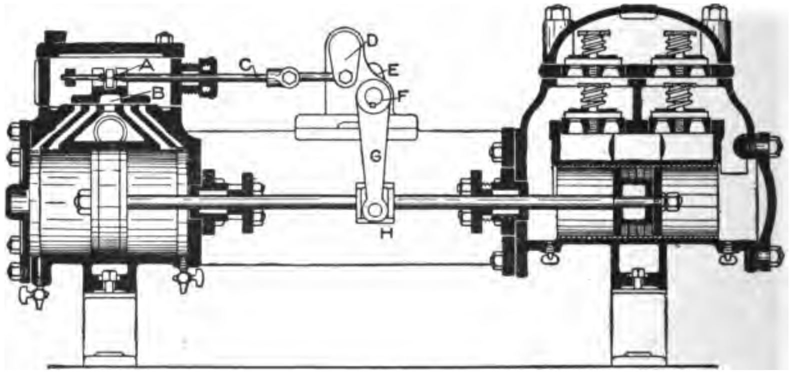


Fig. 70. Duplex Pump Valve.

between them may be adjusted, thereby regulating the cushioning to any desired amount.

In order to secure the rest period at the end of each stroke, which is needed for quiet running and small slip, it is usual to introduce a lost-motion device in the valve-driving mechanism. In Fig. 70 this is the nut *A*, which has a thickness less than the space between the lugs on the valve, thus preventing the valve from being moved until the nut has traveled some distance. In larger sizes it is more common to use a single lug on the valve; the rod passes through this and the lost motion is provided for by adjusting nuts held fast by jam nuts, so that the valve lug will have play between them, Fig. 71. For very large pumps and pumping engines, lost-motion links are usually placed in the end of the valve rod, Fig. 72, by means of which the lost motion may be adjusted without removing the steam-chest cover, or even stopping the pump. This device is, of course, somewhat more expensive to construct than the jam nuts, Fig. 71, and is not often used for small pumps.

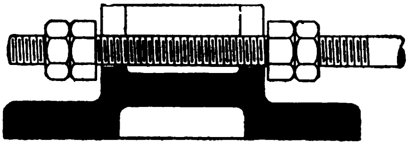


Fig. 71. Lost-Motion Device on Valve.

The amount of lost motion needed for any style of pump can be determined only by trial, but once fixed will be the same for all pumps of a given style and size. For pumps up to 10-inch stroke, $\frac{1}{8}$ inch to $\frac{3}{8}$ inch is usually allowed; for larger sizes the requirements call for $\frac{1}{2}$ inch to 1 inch.

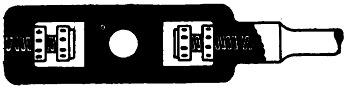


Fig. 72. Lost Motion Links on Valve Rod.

Compound Steam Pump Valves. The simple steam pump must from the nature of its action take steam full stroke, hence has no possibility of using any of the expansive energy in the steam. In order to overcome this difficulty large pumps are often compounded, and usually with cylinders arranged tandem, Fig. 73, or with the smaller cylinder outside, as the designer may choose. Steam from the boiler enters the high-pressure steam chest in the usual way; it then passes to the high-pressure cylinder; from there it exhausts into the low-pressure steam chest through the side pipe at the back of the steam chests, Fig. 73; thence it passes into the low-pressure cylinder and from it to the exhaust pipe. Unless a boiler pressure of more than 80 pounds is used, it is not advantageous to compound a pump run noncondensing, as the saving in steam will not pay for the increased cost. If a condenser is used, compounding may be introduced with profit for pressures as low as 50 pounds; but the added complication of condenser and many cylinders is inadvisable for pumps with low-pressure cylinders smaller than about 18×24 inches.

One of the conditions necessary for the operation of direct-acting steam pumps is that the total force exerted by the steam pistons must at all times exceed that against the water piston.

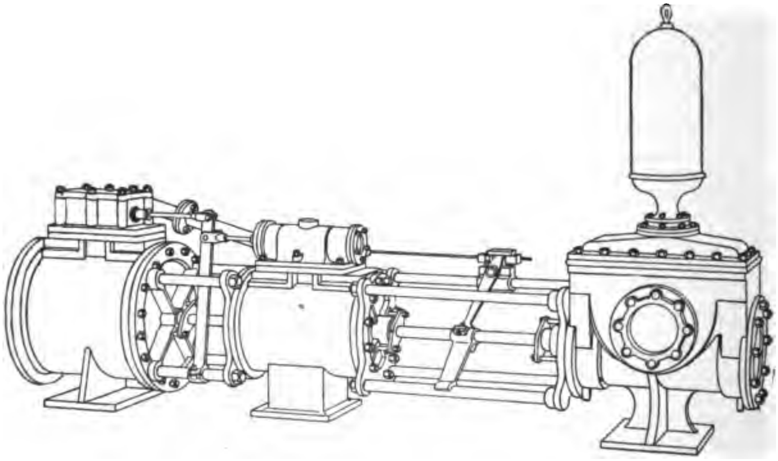


Fig. 73. Compound Steam Pump with Cylinders Arranged in Tandem

In order to overcome this difficulty to some extent a cross exhaust is sometimes used, consisting of a steam pipe connecting the steam chests of the low-pressure cylinders, with a valve in the pipe in order that the amount of steam passing from one side to the other may be regulated to give the best results. By this means the steam from the high-pressure cylinder of one side of the pump exhausts into the steam chest of the low-pressure cylinder of the other side when the piston in the latter has reached about two-thirds stroke. This raises the pressure at the time when it is most needed, but the cross-exhaust valve should never be opened more than enough to finish the stroke.

By carrying out the compounding idea further and using the cross exhaust, manufacturers have developed triple-expansion pumps which have 3 instead of 2 cylinders on each side, the high-pressure cylinder taking steam direct from the boiler and exhausting into the first intermediate space; and the intermediate cylinder with a cross-exhaust connection between intermediate cylinders; one of these cylinders exhausts in turn into the second intermediate space and low-pressure cylinder which is connected by a cross exhaust to the other low-pressure cylinder.

The gain in economy due to compounding direct-acting pumps is best represented by diagrams. A simple pump will have a steam diagram of rectangular shape; in this case all the expansive energy of the steam is wasted by the pump. In the compound pump the combined diagram of the high- and low-pressure cylinders is made up of two rectangles as illustrated. The gain in work due to compounding is represented by that portion of the low-pressure diagram extending to the right of the high-pressure diagram while the loss due to expansion between the high- and low-pressure cylinders is represented by the shaded portion of the diagram.

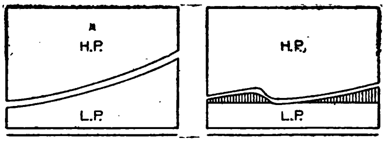


Fig. 74. Diagrams from Compound and Cross-Exhaust Steam Pumps

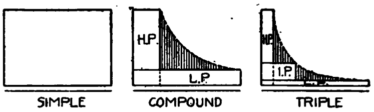


Fig. 75. Comparison of Simple, Compound, and Triple Diagrams

In a similar manner the simple diagrams of a triple-expansion pump are combined, the shaded portion being reduced.

The percentage of gain by compounding varies from 20 to 35 per cent in noncondensing and from 25 to 40 per cent in condensing pumps.

Compound pumps, Fig. 76, are used either single with an auxiliary valve and valve piston or duplex with the valves driven by the method described for duplex pumps.

The high-pressure cylinder takes steam full stroke. At the opening of the high-pressure exhaust, pressure is equalized in the low-pressure steam chest, side pipe, high-pressure cylinder, and the clearance space of the low-pressure cylinder, the admission to which opens

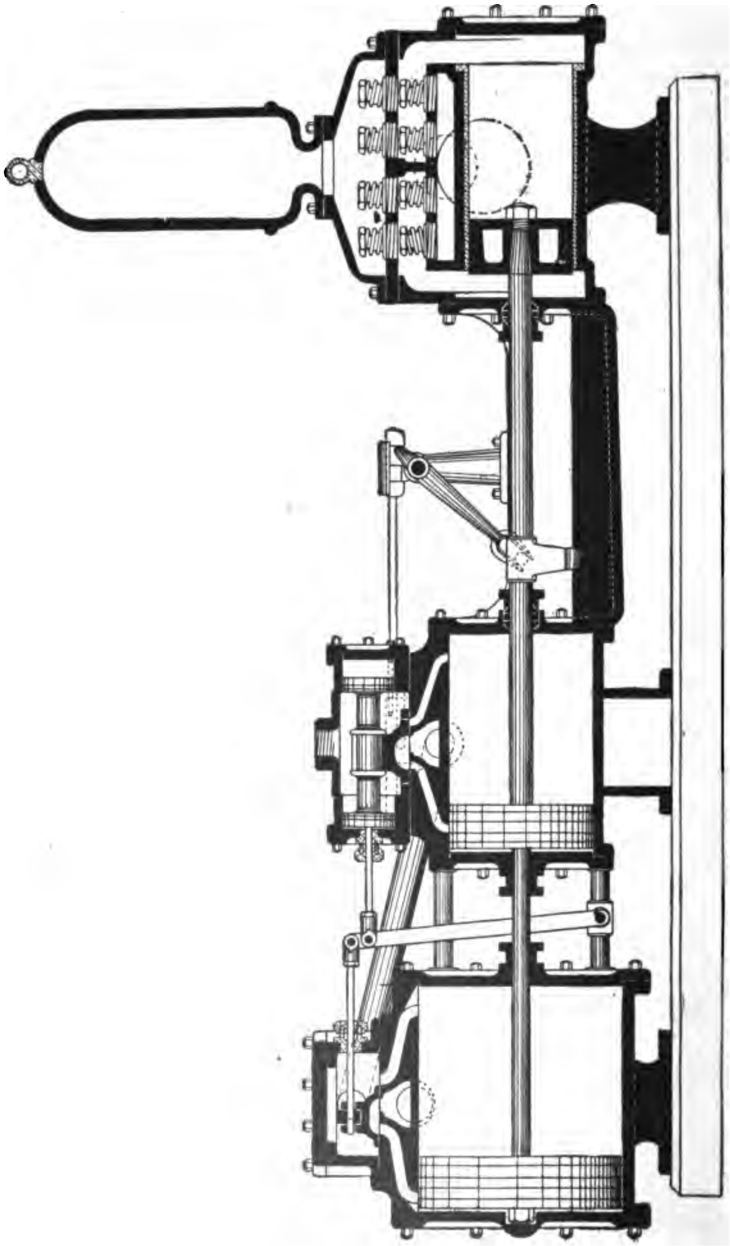


Fig. 76. Compound Steam Pump—Single-Acting with Auxiliary Valve.

at the same instant as the exhaust from the high-pressure. On the return stroke of the pump, the steam expands in passing from the high-pressure cylinder to the low-pressure, the action being as indicated in the diagram, Fig. 77, and the nominal ratio of expansion between 2 and 3. In the diagram it is taken as 2.25, vertical distances being laid off to represent pressures and horizontal distances to represent volumes. The pressure in the passages between cylinders is a variable, but is taken as the value at the beginning of the low-pressure stroke. The back pressure in the low-pressure cylinder will be about 2 pounds above that at the outlet of the exhaust pipe, viz, 17 pounds for a non-condensing, and 4 pounds for a condensing pump.

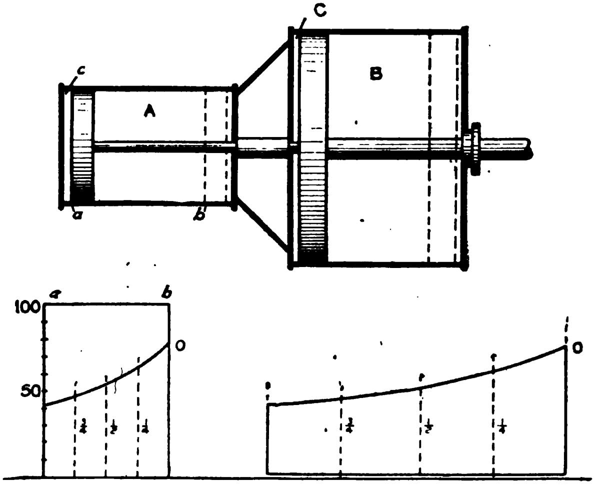


Fig. 77. High- and Low-Pressure Diagram for Compound Pump.

The action, Fig. 77, is as follows: Assume that a pump has a high-pressure cylinder *A*, 16-inch diameter by 18-inch stroke, with a clearance *C* which is 8 per cent of the piston displacement; and a low-pressure cylinder *B* of 24-inch diameter, and with stroke and clearance the same as for the high-pressure cylinder. The intermediate space between cylinders, side pipe, and low-pressure steam chest will be, in practice, about 0.35, the piston displacement of the high-pressure cylinder. Assume that the initial pressure is 85 pounds gauge or 100 pounds absolute and the back pressure in the low-pressure cylinder 4 pounds absolute. The line *ab* will represent the action during admission to the head end of the high-pressure cylinder, steam being taken at full pressure for the entire stroke. If the volume of the piston displacement is considered as 1, there will be 1.08 volumes of steam in the high-pressure cylinder and clearance. At the end of the stroke, the exhaust through the side pipe into the low-pressure cylinder will be opened and the pressure will fall, the amount of the instantaneous drop depending on the pressure in the low-pressure steam chest at the time the high-pressure exhaust opens. This will be about 40 pounds—a value which may safely be assumed as a working basis. When the high-pressure exhaust opens, the admission to the low-pressure cylinder also opens, and the pressure will drop according to Boyle's law, so that it is equalized in the three compartments.

The ratio of the volume of the low-pressure cylinder will be $1.5^2 \times 1 = 2.25$, and of its clearance $.08 \times 2.25 = 0.18$ volumes. Then the pressure after drop and equalization is found thus:

$$\begin{array}{rcrcr} 1.08 & \times & 100 & = & 108.00 \\ .35 & \times & 40 & = & 14.00 \\ .18 & \times & 4 & = & .72 \\ \hline 1.61 & & & & 122.72 \end{array}$$

$$122.72 \div 1.61 = 76.2$$

The pressure after equalization, 76.2 pounds, is found by multiplying each volume by the pressure existing within it and dividing the sum of the products by the sum of the volumes.

As the pistons return, the volume in the high-pressure cylinder decreases, that in the intermediate passages remains constant, and that in the low-pressure cylinder increases. The result will be an expansion according to the hyperbolic law so that the line showing the back pressure on the high-pressure piston, and that showing forward pressure on the low-pressure piston, will indicate the same pressure at each instant of the stroke, though the low-pressure volume will be 2.25 times the high-pressure volume. At $\frac{1}{4}$-stroke the total volume will be

$$.08 + .75 + .35 + .18 + (\tfrac{1}{4} \times 2.25) = 1.92 \text{ volumes}$$

and the pressure

$$122.72 \div 1.92 = 64 \text{ pounds}$$

*TABLE XVII
Compound Pump Data

Ratio diameter of low-pressure to high-pressure cylinder	1.50	1.60	2.00
High-pressure cylinder volume taken as	1.00	1.00	1.00
High-pressure clearance volume	.063	.063	.06
Intermediate space volume	.339	.339	1.12
Low-pressure cylinder volume	2.25	2.56	4.00
" " clearance "	.112	.128	.204
No. expansions intermediate chamber	1.319	1.439	2.250
No. expansions l. p. cylinder	1.825	2.020	2.258
No. expansions, total	2.400	2.907	5.081
Ratio mean effective pressure to (initial pressure minus back pressure)	0.729	0.682	0.466

Similarly at ½-stroke the pressure will be 55 pounds, at ¾-stroke, 84.3 pounds, and at full stroke, 42.9 pounds, and so on for other points, so that the whole expansion curve may be determined. In practice there will be a difference of about one pound between the back pressure in the small cylinder and the forward pressure in the large one, due to the friction of the steam in ports and side pipe. On the next stroke, the head end of the high-pressure cylinder will take a fresh charge of steam while the crank end of the low-pressure cylinder will exhaust its steam into the condenser. The crank end of the small cylinder and the head end of the large one act together in the same manner as described above, so that the pump is double-acting. The proportion of parts of a compound pump are given in Table XVII.

Setting of Valves. Setting the valves on a pump is for the most part a simple operation; it requires only that the valves shall be adjusted, usually by trial, until the pump makes the longest stroke possible without striking the heads, and reverses evenly at the ends of the stroke.

The fly-wheel pump is adjusted by moving the eccentric on the shaft and the valve on its stem until steady running is secured, the same as for any slide-valve engine. The Knowles pump has the stroke lengthened by lowering the roll E, Fig. 64, and shortened, by raising it; equalization of reversal is effected by lengthening or shortening the link L as may be required..

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*Taken from a paper on "Power of Compound Pumping Engines," by John Hill, by courtesy of *Engineering News*.

Adjustment of the Deane pump is made entirely by moving the tappets on the valve rod; the block *A* should be clamped to the piston rod in such position that when the piston is at mid-stroke the link *B* will be vertical. With the valve in mid-position the tappets should be placed so that they are equidistant from each end of the sliding collar, and then adjusted by trial until the working is satisfactory. If the piston strikes at either end, move the tappet at that end towards the collar; if reversal comes too soon at one end, move the tappet away from the sleeve at that end.

For the Dean Brothers pump the same directions apply as to the Deane, but the stroke may be changed by moving the bolt *B*, Fig. 67, in its slot without changing the tappets.

The adjustment of the Blake valve is also the same as that for the Dean Brothers, but the tappets on the valve rod should be so set that the valve will have a little lead, opening before the main piston reaches the end of the stroke.

In the Davidson pump, Fig. 69, the valve is adjusted for length of stroke by moving the bolt in the slotted end of the oscillating arm; shortening the leverage shortens the stroke and *vice versâ*. To equalize the reversal, the sleeve which is clamped to the piston rod may be shifted towards the end at which it is desired to quicken the reversal, or, slight adjustment may be made at the point where the oscillating lever is made fast to the rocker shaft which drives the cam *C*.

For a single compound pump the valves are adjusted in the same way as for a simple pump of the same make. There is an adjustment in the connection between the high- and low-pressure valves, and this must be set, with the steam-chest covers off, so that the main valves open at the same time.

All the valves of the duplex pump are set square so that, with both pistons at the middle of the stroke, the valves will be in mid-position, the rocker-arm levers will be vertical, and the lost motion will have equal play at each end. The amount of lost motion needed, where it is adjustable, can be determined only by trial, but generally should be as great as possible without having the pistons strike the heads. This will give a long stroke.

For the large pumping engines used in city water-works, the steam ends are designed the same as for any steam engine. For

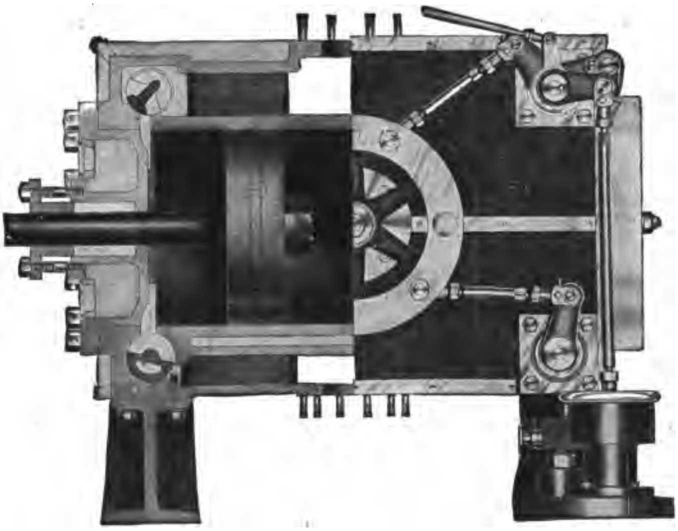

Fig. 78. **Corliss Valve Motion.**

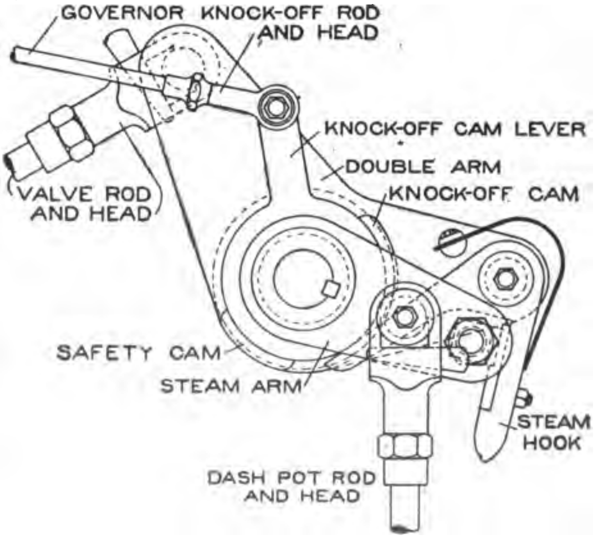

Fig. 79. Trip Motion of Corliss Valve

such engines the Corliss valves and valve motion have been most commonly used in the United States.

The arrangement of the motion and the action of the valves is shown in Fig. 78. The wrist plate is moved by the eccentric through a reach-rod, rocker shaft, and eccentric rod, and from it links run to cranks which turn the rotating valves in their seats. The exhaust valves are positively driven, but the admission valves are so arranged as to be disconnected from the control of the link at some point in the stroke—depending on the position of the governor—by a trip motion, one form of which is shown in Fig. 79.

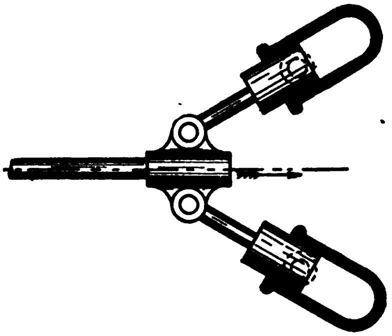

Fig. 80. Hydraulic Compensator.

Another device used to allow of expansive working of steam in large pumps is the hydraulic compensator, Fig. 80. The steam must work against the pressure of the pistons up to half stroke, and is assisted by it beyond that point, so that cut-off may take place at half stroke, or later, and the energy of expansion be used beyond that point. With this device, there is no shaft or eccentric, and valves similar to those described for duplex pumps are used.

ERECTION

Location. The location of a pump should be chosen with two principal objects in view: To have the pump itself convenient for running, and accessible for repairs or adjustment; and to keep the piping as short and direct as possible. A pump to which the liquid is raised by suction should not be more than 20 feet, and never more than 25 feet above the source of supply; but aside from this, a matter of first importance is to have the machine where it will naturally be kept in good condition. Too often a pump is placed in a dark corner where it is never seen, seldom visited, and always neglected; it soon becomes dirty and leaky, thereby decreasing its efficiency and shortening its life. The second point with respect to piping is often controlled by the layout of other apparatus quite as much as by the position of the pump itself; yet by careful study of the conditions it is often possible to find one place better than others for the pump. It is of more importance to avoid bends and elbows in water piping than in that for steam, because steam makes sharp turns with less friction loss than does water. If hot water is to be handled, the water should flow to the pump by gravity or under pressure. Otherwise the water will turn into vapor under the suction force and the pump will draw in either vapor alone or a mixture of vapor and water.

It is well to place a boiler feed pump in such a position that the gauge glass may be seen when standing at the pump, but this is not absolutely essential, and should be sacrificed if any gain in arrangement of piping or convenience of attendance can be secured thereby. If a condenser air-pump is so placed that the water from the condenser flows to it by gravity, it is possible to maintain a better vacuum in the condenser.

Foundation. For pumps of large size the foundations which are provided should be very substantial especially if the pumps are to be run at high speed. It is often sufficient to fasten a small pump to the floor or to heavy brackets secured to a wall, but a pump larger than a 4 × 6 should have a separate foundation deep and narrow, rather than broad and shallow, unless the pump is large and the soil very sandy. In designing the foundation, remember that the object is not only to support the pump but to hold it so firmly as to prevent vibration; the pump should therefore be well bolted to the foundation so that no movement is communicated to the pipe and thence to the building, as this tends to loosen the joints in the piping and in the pump itself. Absolute rigidity on the foundations should be secured at any cost.

The material may be stone, brick, or concrete, preferably the last as stone is expensive and difficult to work; brick is liable, unless carefully laid with cement mortar, to work loose; but concrete is easily put down, is inexpensive, and has all the solidity of stone. It should be made of good cement mortar—two parts sand to one part Portland cement—mixed with broken stone not over 2 inches in longest diameter, in equal parts of stone and mortar. The concrete should be well compacted into a mould the shape of the foundation, the bolts being built in with plate-iron washers on the heads; the concrete should be deposited in layers about 6 inches deep and well rammed, a second layer being added before the upper surface has hardened. This process is repeated until the foundation is completed. It will generally be sufficient to finish the top with a surface of cement mortar, carefully leveled and allowed to harden before setting the pump, but sometimes a cast-iron base-plate is used, and this gives a somewhat neater appearance.

PIPING

As previously stated, the piping should be as short and direct as possible. In large work, the water pipe should have long-bend elbows and tees, and gate valves should be used to reduce the friction. Each pipe should be pitched throughout its length to one point so that it may be drained to avoid freezing; a drain cock should be placed at the lowest point to remove the water. For water piping, it is well to use galvanized or brass pipe to avoid pitting or corrosion. Covering the pipes which carry cold water will prevent sweating and the consequent unpleasant dripping.

Duplicate System. If the plant is one where a shut-down would be serious, a duplicate system should be installed, pump, piping, and all; for any plant it is well to provide an injector as relay, in case the boiler feed-pump will not work. In some cases duplicate piping is installed, but this seems hardly necessary, as piping is not likely to get out of order if well taken care of.

Check Valves. Wherever a long column of water is to be moved in either suction or delivery pipes, it is well to place a check valve near the lower end of the column to resist any tendency of the water to back up when the pump reverses or shuts down. In the suction system this valve would be placed on the inlet end of the suction pipe and is known as a *foot valve,* Fig. 81. For the delivery pipe, it is

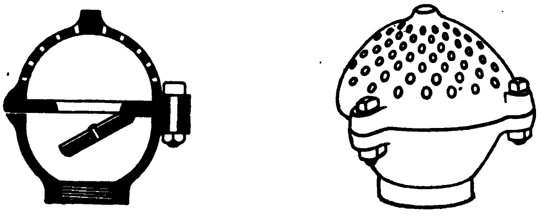

Fig. 81. Foot Valve on End of Suction Pipe.

well to use a check valve near the outlet from the pump and another near the end of the pipe, especially if pumping against high pressure. The check valves may be of either the flap type, Fig. 82, or the disk type, Fig. 83, but if of the latter, they should have ample area so that the double turn made by the current of water will not cause great loss of head.

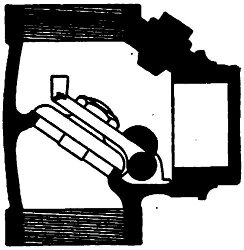

Fig. 82. Flap Check Valve.

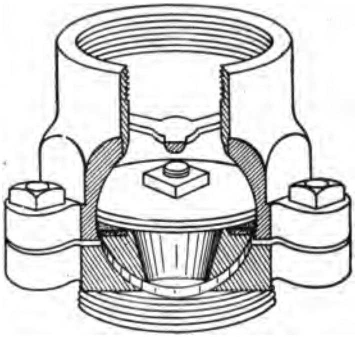

Fig. 83. Disk Check Valve.

Strainer. For all pumps which are to handle water from ponds, rivers, or other sources where sticks, leaves, or any form of rubbish is likely to collect, a strainer, Fig. 68, should be placed on the end of the inlet pipe. The combined area of the openings into the strainer should be 3 to 4 times the area of the pipe. As rubbish quickly collects on a horizontal strainer, the surface should be either slanting or vertical, and should be so designed that the screen may be easily cleansed. The straining surface should be fine or coarse in mesh according to the material to be screened, and made of woven wire or perforated metal as may be most convenient. Often the foot

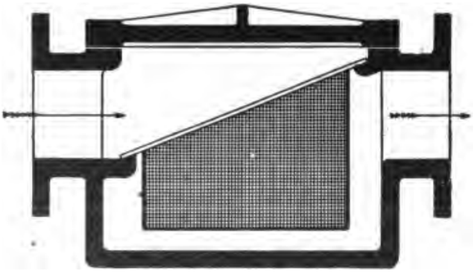

Fig. 84. Barr Strainer.

valve and the strainer are combined into a single piece. If the lower end of the suction pipe is not accessible for cleaning, and if the débris is of such nature that it is likely to clog the openings, it will be better to use a design given by Barr, Fig. 84, placed near the pump.

Sizes of Pipe. The size of pipe needed for the suction and the delivery are determined by the pump maker and the pipes should never be made smaller than the sizes recommended; if the runs are long, the pipes may well be made larger.

The velocity allowable is, of course, the point which determines these diameters. For the suction, this is usually taken at 200 feet per minute or less; for the delivery pipe it may be 400 feet per minute or less.

The suction pipe should be of the same size throughout in order to avoid eddies and changes of velocity. Where the pipe is larger than the pump connection, the reduction should be made by a conical pipe with an easy taper, placed next to the pump. The greatest care should be taken to see that all joints in the suction system are absolutely tight, as even a small leak greatly reduces the capacity and the efficiency. The diameters of pipe suitable for direct-acting pumps are given in Table XVIII.

TABLE XVIII

Sizes of Suction and Delivery Pipes

Suction velocity, 150 feet per minute; delivery velocity, 300 feet per minute; piston speed, 100 feet per minute.

Diameter Water Cylinder	Diameter Suction Pipe		Diameter Delivery Pipe	
	Single Pump	Duplex Pump	Single Pump	Duplex Pump
4 inches	2½ inches	3½ inches	1¾ inches	2½ inches
5 "	3 "	4 "	2 "	3 "
6 "	3½ "	5 "	2½ "	3½ "
7 "	4½ "	6 "	3 "	4 "
8 "	5 "	7 "	3½ "	4½ "
9 "	6 "	8 "	4½ "	6 "
10 "	6 "	8 "	4½ "	6 "
12 "	7 "	10 "	5 "	7 "
14 "	9 "	12 "	6 "	8 "
16 "	10 "	14 "	7 "	9 "
18 "	12 "	16 "	9 "	12 "
20 "	12 "	17 "	9 "	12 "

The loss in head depends on the length of the piping and the rate of flow of the water. Table XIX gives the loss in pounds pressure per 100 feet of pipe for various rates of discharge and sizes of pipe as stated by G. A. Ellis.

The loss of head from elbows and valves depends also on the rate of flow, and is most conveniently referred to the length of pipe which would result in the same loss.

The resistance to flow of water in pipes due to bends, elbows, tees, etc., is expressed by the equation*

$$P = F \frac{v^2}{64.4}$$

in which P is the loss in pressure in pounds per square inch, v, the velocity of flow in feet per second, and F, the coefficient of friction, which varies with the angle of the bend according to the following:

Angle	20°	45°	60°	90°	120°	135°
F	.020	.079	.158	.426	.806	.940

A globe valve will produce the same loss of head as two 90-degree bends, and a gate valve, a loss equal to a 45-degree bend.

If water is known to contain lime or magnesia, it is certain that pipes will fill up more or less from the deposit of scale, and allowance should be made for this in the first place by using extra large pipe.

In choosing the size of steam pipe the same general principle applies; the exhaust pipe, like the suction, should be short, direct, and of ample cross-section. A velocity of 6,000 feet per minute is allowable in the steam pipe and 4,000 feet in the exhaust.

Care should be taken to have all piping which carries live steam pitched toward the pump and a drip chamber provided to avoid the passage of the water of condensation to the steam cylinder, and drips should be provided wherever there is any chance for water to collect.

Air chambers are usually a good investment if high speed or long pipe runs are to be used, for the gain in durability and saving of repairs to the pump and piping system will more than pay the interest on the small cost of their installation. Care should be taken, however, that no pockets are formed in the piping where air may collect, as the air cushion thus formed will serve no useful purpose,

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*Foster, *Electrical Engineer's Pocket-Book.*

*TABLE XIX

Friction of Water in Pipes

Gallons per Minute	SIZES OF PIPES—INSIDE DIAMETER													
	¾ in	1 in.	1¼ in.	1½ in.	2 in.	2½ in.	3 in.	4 in.	6 in.	8 in.	10 in.	12 in.	14 in.	16 in.	18 in.
5	3.3	0.84	0.31	0.12	0.05	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
10	13.0	3.16	1.05	0.47	0.12	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
15	28.7	6.98	2.38	0.97	0.30	0.11	.....	.....	.....	.....	.....	.....	.....	.....	.....
20	50.4	12.3	4.07	1.66	0.42	0.15	.....	.....	.....	.....	.....	.....	.....	.....	.....
25	78.0	19.0	6.40	2.62	0.51	0.21	0.10	.....	.....	.....	.....	.....	.....	.....	.....
30	.....	27.5	9.15	3.75	0.91	0.33	0.11	.....	.....	.....	.....	.....	.....	.....	.....
35	.....	37.0	12.4	5.05	1.20	0.45	0.17	.....	.....	.....	.....	.....	.....	.....	.....
40	.....	48.0	16.1	6.52	1.60	0.52	0.22	.....	.....	.....	.....	.....	.....	.....	.....
45	.....	.....	20.2	8.15	2.00	0.65	0.28	.....	.....	.....	.....	.....	.....	.....	.....
50	.....	.....	24.9	10.0	2.44	0.81	0.35	0.09	.....	.....	.....	.....	.....	.....	.....
75	.....	.....	56.1	22.4	5.32	1.80	0.74	0.17	.....	.....	.....	.....	.....	.....	.....
100	.....	.....	.....	39.0	9.46	3.20	1.31	0.33	0.05	.....	.....	.....	.....	.....	.....
125	.....	.....	.....	.....	14.9	4.89	1.99	0.53	.....	.....	.....	.....	.....	.....	.....
150	.....	.....	.....	.....	21.2	7.0	2.85	0.69	0.10	.....	.....	.....	.....	.....	.....
175	.....	.....	.....	.....	28.1	9.46	3.85	1.00	.....	.....	.....	.....	.....	.....	.....
200	.....	.....	.....	.....	37.5	12.47	5.02	1.22	0.17	.....	.....	.....	.....	.....	.....
250	.....	.....	.....	.....	.....	19.66	7.76	1.89	0.26	0.07	0.03	0.01	.....	.....	.....
300	.....	.....	.....	.....	.....	28.06	11.2	2.66	0.37	0.09	0.04	.....	.....	.....	.....
350	.....	.....	.....	.....	.....	.....	15.2	3.65	0.50	0.12	0.05	0.02	.....	.....	.....
400	.....	.....	.....	.....	.....	.....	19.5	4.73	0.65	0.16	0.06	.....	.....	.....	....
450	.....	.....	.....	.....	.....	.....	25.0	6.01	0.81	0.20	0.07	0.03	.....	.....	.....
500	.....	.....	.....	.....	.....	.....	30.8	7.43	0.96	0.25	0.09	0.04	0.017	0.009	0.005
750	.....	.....	.....	.....	.....	.....	.....	.....	2.21	0.53	0.18	0.08	.....	.....	.....
1000	.....	.....	.....	.....	.....	.....	.....	.....	3.88	0.94	0.32	0.13	0.062	0.036	0.020
1250	.....	.....	.....	.....	.....	.....	.....	.....	.....	1.46	0.49	0.20	.....	.....	.....
1500	.....	.....	.....	.....	.....	.....	.....	.....	.....	2.09	0.70	0.29	0.135	0.071	0.040
1750	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.95	0.38	.....	.....	.....
2000	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1.23	0.49	0.234	0.123	0.071
2250	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.63	.....	.....	.....
2500	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.77	0.362	0.188	0.107
3000	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1.11	0.515	0.267	0.150
3500	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.697	0.365	0.204
4000	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.910	0.472	0.263
4500	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.593	0.333
5000	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.730	0.408
Comparative Discharging Power of Pipes	$\sqrt{d^5}$	1	1.75	2.76	5.66	9.88	15.59	32.	88.2	181	316.2	498.8	733.4	1024.	1375.

but will reduce both the capacity and the efficiency of the pump. The suction pipe should have a continuous rise from the source of supply up to the pump; and if an inverted U-loop must be formed in the delivery piping it should have a pet cock inserted at the highest point so that whatever air collects may escape

CARE

After the valves of a pump are properly adjusted, the things ordinarily requiring care are: lubrication, packing, and draining of cylinders.

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*Friction loss in pounds pressure per square inch, for each 100 feet of length of different sizes of clean iron pipe discharging given quantities of water per minute.
G. A. Ellis, C. E.

Lubrication. For smaller sized pumps, the steam end is generally lubricated by means of a grease cup, filled with some form of tallow compound which, as it is gradually melted by the heat of the steam, flows into the steam chest and is carried by the steam to the cylinder. For larger sized pumps a regular cylinder oiler is used, or sometimes an oil pump driven by a lever from the main piston rod. In large plants, the pumps as well as the engines are fed from a central tank into which the oil is forced under pressure by a single large oil pump, and whence it descends by gravity to the various cylinders and passes through sight-feed oilers.

The stuffing-box on the steam end usually gets sufficient lubrication from the cylinder, the one on the water end gets water enough except when the packing is set up hard, in which case a little machine oil with graphite in suspension will help.

In the case of the steam cylinder, as for any other engine, the less oil used, so long as the piston works quietly, the better.

Flake graphite put into cylinder oil usually settles to the bottom of the cup, but if blown into the steam pipe so as to be carried along by the steam, it will work into the crevices in valves and piston rings and aid materially in reducing the oil required; it also will reduce the friction considerably if sifted over the packing when filling the stuffing-boxes.

For the bearings of valve motions, machine oil is, of course, used. These parts need the same care as any other machine bearings.

Packing. The packing in the water piston wears but slowly; nevertheless it should be regularly inspected to make sure that there are no leaks, as they would seriously impair the economy of the pump. It should be the rule to examine the water pistons at least once in two months and oftener, if there is any reason to suspect trouble. In repacking, or in tightening up either piston or stuffing-boxes, there should be as little pressure as possible, above the limit to prevent leakage.

The piston ring packing of the steam end will wear for years if properly adjusted and lubricated. An inspection once a year is sufficient unless suspicious action in the cylinder seems to call for an investigation.

The stuffing-boxes should be kept tight, but not screwed up so as to bind. It pays to be rather generous both in the amount of packing used in a stuffing-box and in the frequency of renewals; in the first case a long bearing between rod and packing will keep tight with less pressure than a short one; in the second case old, hardened packing requires a heavy pressure to force it to a tight joint, and results in a large amount of energy wasted in overcoming friction. For stuffing-boxes, any good square packing will answer, but the one on the water end is better filled with some form having a rubber compound for its main body, while that on the steam end works better with a flax packing, as the steam soon kills the rubber. Stuffing-boxes should be refilled as often as twice a year, if the pump is in constant service.

Valves. The valves in the steam end have a sliding bearing, and will ordinarily wear to a true and tight joint. At the time of the yearly inspection, the head should be removed, steam turned on, and the valve worked back and forth by hand to make sure that no steam passes into the cylinder except when the admission valve is properly open. If the valves leak, they must be scraped to a bearing. Usually the valve face is scraped accurately by using a surface plate, and the seat is then scraped to fit the valve.

The valves in the water end may be reseated by grinding the seats and faces with tools made for the purpose, if both the valves and seats are of metal. If the valves have a bearing surface of composition, as is now the usual practice, the composition disk will wear rather than the seat, and the disk may be renewed easily and at slight expense. Some makers use disks of soft alloy which have all the advantages of composition and are more durable.

In discussing the subject of capacity, the matter of speed was taken up. Manufacturers conventionally rate their pumps at 100 feet per minute, but this is not a good basis, and sixty double strokes seem to be more logical for computation. The object is to reduce slip and prevent pounding; hence, if special devices are used for opening and closing the water valves and to prevent slamming at the end of the stroke, there is no reason why a speed may not be used approaching that of power engines. The slip occurs almost entirely at the ends of the stroke and during the seating of the valves, so that it is always well to use a long stroke even though the diameter be somewhat small.

If mechanically operated valves together with high speed are used, ample air chambers should be placed on suction and delivery systems, as otherwise there is likely to be water hammer due to the sudden stoppage of the column of fluid in the pipes when the valves close.

There is no difficulty with the steam end in using high speeds provided the steam is kept free from water. This necessitates, in the case of large pumps, a separator in the steam pipe just above the pump, to remove all water and insure the passage of none but dry steam.

Operating Troubles. *Slamming.* It is impossible to forewarn against all difficulties which may arise in running a steam pump, because it is always "something different" which happens, but trouble can often be traced to certain common faults. Defective valves in the water end and stoppage in the suction pipe are the probable causes for irregular working of a single pump. If the pump slams on one stroke and is steady on the other, it may be that the discharge valves are stuck open on one end either by friction or the lodgment of some substance on the seat. Often a jar with a hammer will remedy this defect, but it is advisable to take off the valve-chamber cover to find the reason for the sticking. If the slamming is on both strokes, it is generally due to stoppage in the suction pipe or, in the case of a pump newly erected, it may be that the suction is too small. If the latter is the case, slowing down will stop it; but if there is stoppage, the pump will slam at all speeds. If the suction is small, the addition of a suction air chamber will sometimes be beneficial. Slamming may also be due to a leak in the suction system, in either valves or joints, or to a leak in the piston packing. Occasionally the springs on the inlet valves are too strong, though this is seldom the case. When starting up, air in the pump may cause it to slam, the remedy being, of course, to prime the pump and suction pipe by pouring in water, and to make sure, by opening the air cock on top of the water end, that all air is forced out of the valve chamber. In a new design of pump, it may happen that a pocket is so located in the pump cylinder that air will be caught between the inlet valves and piston and trapped. This will produce air binding and slamming and can only be remedied by filling up the pocket or tapping it with an air cock so that the air can be drawn off as it collects. This is not likely to occur in a standard type of pump, as such a defect would be detected and remedied by the maker.

A hard metallic knock just before the end of the stroke is usually due to water hammer in the steam end and can be remedied by opening the drip in the steam cylinder. If it continues, the steam chest should be drained by a drip pipe to carry away the water before it enters the steam cylinder.

The power of boiler-feed pumps can be considerably increased by piping the exhaust into the suction pipe, if the exhaust steam is not needed for other purposes. In this way the water serves to condense the exhaust steam, and the exhaust steam heats the feed water. This heating cannot, of course, be carried to the point where the temperature of the water interferes with the suction of the pump end.

Sticking. If a pump sticks at the end of the stroke, it is due to friction or improper valve setting. In the former case, relieving the pressure on the nuts, which set up the glands to the stuffing-boxes, until there is just enough pressure to prevent leakage will overcome the difficulty. In the latter case the valve motion should be so adjusted as to act earlier in the stroke, but it is best to keep the stroke of the pump as long as possible in order to reduce the loss from clearance in the steam cylinder.

Starting. In starting up, particularly in cold weather, there will be considerable condensation in the steam cylinders and water will form rapidly. This must be given a chance to work its way out through the drips which should be left open until the pump runs free and without any sign of water in the steam; the warming up should be done at slow speed.

If a cylinder oiler is used it should be opened up a sufficient time before the pump is to be started, so that it may be ready to act immediately when the pump starts, as the lubrication is needed when the cylinder is cold, even more than at any other time. It is well to have a hand-forcing oil pump connected to the steam pipe of large pumps unless the feed of oil is by a positively-driven pump, so that in starting up or in case of emergency a supply of oil may be insured.

Before starting, the suction and outlet valves should be inspected to make sure that both are open. If a start is made with these closed, it is likely to bring a pressure on the systems which will open the joints.

If the pump is a large one and is run condensing—*i.e.*, exhausting into a condenser—the condenser should be put in operation first, by starting the flow of cooling water and the air pump. When these are both working well and a good vacuum has been established, the main pump may be started.

Stopping. In closing down, the lubricators may be closed a little before the time to stop. The drips on the steam cylinder should be opened after stopping in order to carry off the condensation from any steam which may remain. The drips on the water cylinder need not be opened unless there is danger of freezing, in which case the whole water system should be drained. For this purpose the piping should all pitch toward the pump so that the water may all be drawn off at that point, if possible.

Short Stroke. In the duplex type of pump, unless the packing be adjusted with an even pressure on both sides, the side on which the tighter adjustment is made is liable to *short stroke;* in fact, this is usually the trouble with a pump which goes *lame* on one side. If the short stroking is on one end only, it is probably due to poor setting of the valve-motion tappets. Short stroking may also be due to tight packing on the water piston, in which case it may be remedied by taking out the packing and cutting off a little. This is likely to occur only with pistons packed with square packing, as those having the cup leather packing or piston rings adjust their own pressure between the piston and cylinder.

In setting up a new pump, it is important to blow out all pipes before making the connections, in order to make sure that no chips or dirt get into the pump. Unions should be provided on each pipe near the pump, so that, in case of suspected stoppage of the pipe, it can be readily inspected.

In centrifugal pumps, the speed requires a substantial foundation, which is best made of concrete with foundation bolts. No piping should be attached to a centrifugal pump until it has been properly erected and the grouting hard and dry, and care should be taken not to spring the pump when attaching the piping.

TESTING

The power used by a pump is usually so small an item in the running expense of a plant, that a test is considered unnecessary; and also the steam exhausted is often used for heating feed water or for some industrial process. If this is possible, it is usually an economical way of running; but in plants where many pumps are needed and where heating feed water is the only use for the exhaust steam, more steam will be available than can be used to good advantage; this is especially true if the main engines run noncondensing. An economical pump is then of great importance.

Duty. In order to determine the good or bad performance of a pump, it is necessary to test it for efficiency and slip, the test being known as a *duty trial.* The duty of a pump, as the term descended to us from the days of Watt's early pumping engines, was the number of foot pounds of work produced by 100 pounds of coal. This is a convenient basis for comparison of engines but is not accurate, as coal varies so much in heat value; also this method of reckoning involves the efficiency of the boiler as well as that of the pump. As an attempt to eliminate the latter source of error in making comparisons, a conventional assumption has been made of 10 pounds of steam evaporated per pound of coal; but this is really only the substitution of one error for another, for one pound of steam when measured in heat units is by no means a constant, and one pound of coal seldom does evaporate 10 pounds of steam in actual boiler performance. The more logical method of comparison is by the duty per 1,000,000 heat units furnished to the pump, a basis proposed by a committee of the American Society of Mechanical Engineers appointed to formulate a code for conducting such tests.

The duty of the pump is found by measuring the quantity of water delivered and the height through which it is lifted, or its pressure equivalent. The coal or steam used must also be measured. Then

$$\text{duty} = \frac{QH \times 100}{C}$$

in which Q = pounds of water delivered, H = head against which the pump works, both suction and forcing, and C = pounds of coal burned. Or on the new basis

$$\text{duty}=\frac{QH\times1000000}{\text{B.t.u.}}$$

in which Q and H are as before, and the B.t.u. is the heat units in the coal or steam, whichever is measured.

An inaccurate method of computing duty is sometimes used, which is based on the area of the water piston, or plunger, and its travel; but this takes no account of the slip which may, in small pumps, be as much as 20 per cent; hence it is to be condemned.

Slip. The slip is found by comparing the water actually delivered with the total piston, or plunger, displacement for the time of the test. The difference, measured as a per cent of the piston displacement, is the slip.

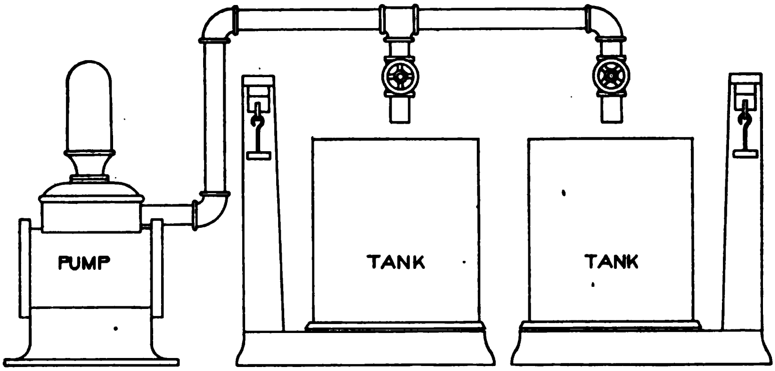

Fig. 85. Tank Arrangement for Testing Water Flow

Water Delivered. The water delivered is measured by weighing, by the use of calibrated tanks, by a weir, or by some form of meter. One of the first two methods is best for small pumps, and the meter is practically the only means available for large ones where the delivery is into a closed pipe system. For the weight or tank method, the arrangement, Fig. 85, is used, one tank being filled while the other is being emptied through a quick opening gate valve. A certain amount is run into the tank and the exact weight is caught after the valve is closed and the water is flowing into the other tank. For calibrated tanks, the filling is done nearly to a set mark, at which the capacity of the tank is known, and the exact level is obtained by dipping from the second tank.

The weir can be used only where the delivery is into an open vessel, as the current of water must be made to flow over an open notch, Fig. 86. The amount of water which passes this notch evidently depends on its length and on the head of water above the sill. There is a certain contraction as the water enters the notch; but if the edges are beveled to a sharp edge up stream, as shown, this will be slight. The depth of the notch should be not over $\frac{1}{2}$ the length and is better made considerably less, say, from $\frac{1}{10}$ to $\frac{1}{4}$. The over-fall below the notch should be at least twice the depth of the notch. The head of the water over the sill should be measured at a point some distance back of the notch in order to get a quiet even surface.

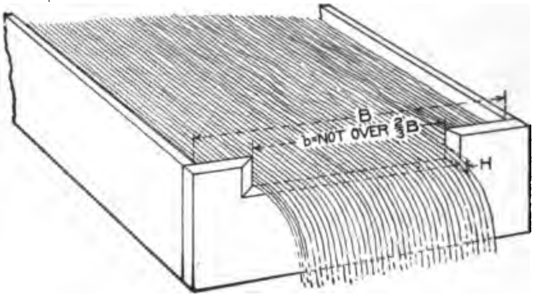

Fig. 86. Weir Showing Standard Dimensions for Tests

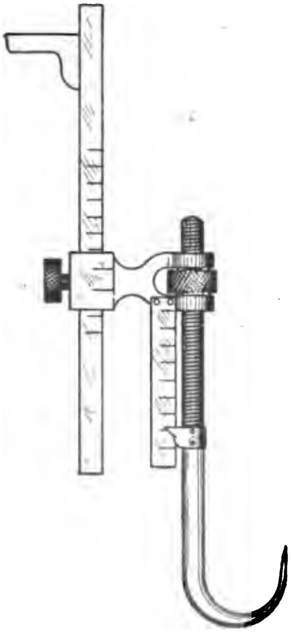

Fig. 87. Hook Gauge

Head. Any method of measuring the head will answer which gives it accurately; but a hook gauge, Fig. 87, will give the best results. The reading of the gauge should be taken when set so that the point just breaks the surface as it is brought up from below, when no water is flowing over the notch. This gives the height of the sill from which to calculate. When the water is flowing from the pump, a reading from the gauge is again taken as the point just breaks the surface. The difference between the two readings is the head above the sill.

Flow. The flow, if there were no end contraction, would be $Q = bvh$, where Q is the cubic feet per second, b the length, h the head of water above the sill, and v the velocity in feet per second. But $v = \sqrt{2g\frac{h}{2}}$ the same as for falling bodies, $\frac{h}{2}$ being used because it is the head of the center of flow. It has been found by experiment that there is a contraction at the ends and bottom of an opening, due to the in-rush of the water from all sides, and that the flow will be about .62, the theoretical amount; hence

$$\begin{aligned} Q &= .62\ bh\sqrt{2g\frac{h}{2}} \\ &= .62\ bh\sqrt{gh} \\ &= .62\ bh^{\frac{3}{2}}g^{\frac{1}{2}} \end{aligned}$$

in which g is the acceleration due to the force of gravity and is equal to 32.16; hence $.62 \times g^{\frac{1}{2}} = 3.52$ and $Q = 3.52\ bh^{\frac{3}{2}}$.

It is found, however, that for accuracy the formula must be modified to take account of the depth of the water, and also that the coefficient is too large. Smith gives, in his *Hydraulics*, the equation

$$Q = 3.29\ (b + \frac{h}{7})h^{\frac{3}{2}}$$

which is accurate for weirs for depth h, from 6 inches to 2 feet, and with length b not less than $3h$. For large quantities of water which must be delivered under pressure, the Venturi meter is the most accurate means of measurement. This is a patented device manufactured by the Builders Iron Foundry of Providence, R.I., and registers the flow by means of a recording mechanism driven by clockwork. The next best device is some form of rotary water meter, carefully calibrated. These will work well with cold water but are not to be relied upon with hot water as the varying temperatures affect the readings appreciably.

***Methods.** For a small power-driven pump it is necessary to measure the power supplied. If belt-driven, this can best be done by means of a transmission dynamometer which measures the pull on the belt. Then this pull in pounds times the speed of the belt in feet per minute equals the foot pounds per minute; and that quantity divided by 33,000 gives the horse-power. The work performed per minute will be the weight of water pumped per minute times the distance through which the water is raised as indicated by gauges on the suction and delivery pipes near the pump. These heads can be derived from the ordinary pressure-gauge readings given in Table III. The work per minute divided by 33,000 gives the delivered horse-power. For a motor-driven pump, the power applied can readily be obtained by electrical measurements. Measure the voltage and amperes of current with the pump carrying its load and then voltage$\times\frac{\text{current}}{746}=$ horse-power for direct current. For alternating current, a wattmeter must be used and the readings divided by 746. From an efficiency curve of the motor, as supplied by the makers or obtained by a dynamometer test of the motor, get the efficiency at the horse-power thus found. Multiply the horse-power by the efficiency and the product will be the power supplied to the pump.

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*For method of testing large pumping engines, the student is referred to the report of the committee of the American Society of Mechanical Engineers, Vol. XI of the Transactions, which may be obtained from the Society in pamphlet form at nominal cost.

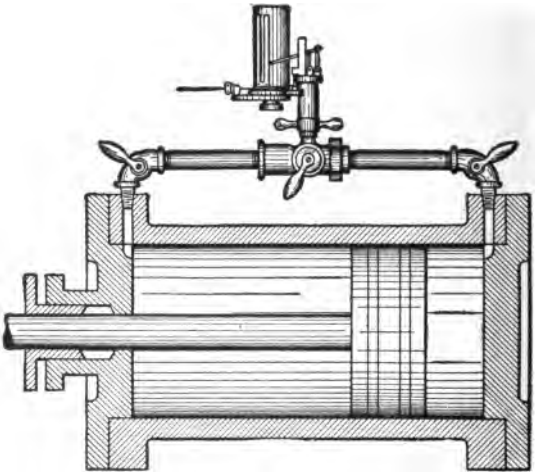

Fig. 88. Section of Steam Cylinder Showing Mounted Indicator

The power delivered by it in the form of water pumped is found by the same method as for the belted type.

For a steam-driven pump, it is necessary to attach an indicator to the steam end in order to measure the power supplied by the steam. The indicator, Fig. 88, is connected to register the pressure in the cylinder at each point of the stroke. The average of these pressures is then found, measuring between the lines indicating the steam and exhaust pressure, Fig. 89. The sum of lines 1, 2, 3, 4, etc., divided by the number of lines gives the average length, and this multiplied by the scale of the spring, or pounds pressure represented by one inch of height, will give the average effective pressure. The scale of the indicator spring is always found stamped on the cap at one end of it. This average pressure multiplied by the area of the piston in square inches, by the length of the stroke in feet, and by the number of double strokes made per minute gives the work done per minute in one end of the cylinder. In the same way pressure times area, times length, times number of strokes gives the work for the other end, and the sum of these amounts divided by 33,000 gives the horse-power developed. It should be noted that there is a difference between the areas of the two ends of the piston owing to the insertion of the piston rod in one end.

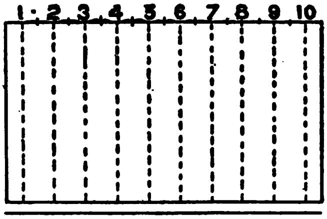

Fig. 89. Graduated Indicator Card

Sometimes the work done in the water cylinder is measured by using the indicator in the same way as described for the steam end. A stiff spring must be used to guard against injury at reversal of the stroke. The work done by the water piston can, of course, be found by this method; but there is nothing to show whether the work is used in pumping water or in slip and leakage, except that a slow seating of the valves may show in a reduced average pressure from the diagram, Fig. 90.

To test the leakage past the piston, one cylinder head may be removed and the pump run single-acting, the water which passes the piston into the open end of the cylinder being caught and weighed. This does not, however, measure the leakage due to faulty valves or seats, and the only way this can be found is by measuring the water actually pumped.

The slip is then found as follows: Multiply the area of the water piston by its length of stroke and by the number of double strokes if single-acting, or single strokes if double-acting—all dimensions being taken in feet—to get the number of cubic feet of water which would be pumped per minute as obtained by measurement; subtract the water actually pumped and divide the remainder by the computed volume which should be delivered. The quotient expressed as a percentage is the slip. Slip is due to the leakage past the piston plunger and through the valves, and the amount varies with the condition of packing and seats and with the promptness of valve closure. It can be kept at a minimum by careful attention to packings and by running slowly and steadily to allow the valves time to seat.

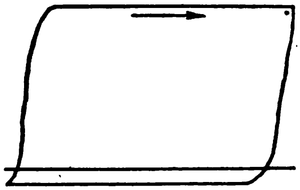

Fig. 90. Indicator Diagram

The efficiency of the pump may be expressed according to various standards. If efficiency as a machine, or mechanical efficiency, is desired, it is found by dividing the horse-power utilized in pumping water by that furnished to the pump by belt, motor, or steam cylinder. If efficiency of the water end is wanted, it is found by subtracting the percentage of slip from 100. The total efficiency is the mechanical efficiency multiplied by the pump efficiency.

To find the "duty", the work done in a given time is found by one of the processes already indicated; the heat furnished during that time is computed from the coal burned and the efficiency of the boiler, or better, by condensing the steam used in a surface condenser and weighing it—or a steam flow meter may be used instead of condensing the steam—and calculating the heat needed to evaporate that amount of steam, starting with water at the temperature of the exhaust steam. Reduced to the form of an equation this becomes

$$\text{duty} = \frac{\text{foot pounds of work done}}{\dfrac{\text{heat units used}}{1000000}}$$

Foot pounds work equals weight of water multiplied by equivalent head overcome. Heat units used equals pounds of steam used times (total heat at initial pressure minus the heat of the liquid at exhaust pressure).

The values inside the parenthesis must be obtained from tables of the properties of saturated steam, which are given in "Boiler Accessories," works on the steam engine, or engineering handbooks.

For a *power-driven* pump, the duty is found by the formula

$$\text{duty} = \frac{\text{foot pounds of work done}}{\dfrac{\text{foot pounds furnished the pump}}{778 \times 1000000}}$$

since 778 foot pounds are equivalent to one heat unit.

For a *motor-driven* pump, the foot pounds are equal to average watts times time in hours times 2,654.2. The watts, in the case of direct current, equal volts times amperes. In the case of alternating current, the watts must be read from an indicating wattmeter or by taking the difference in readings of a recording watt-hour meter and dividing this difference by the time in hours between readings.

REVIEW QUESTIONS

REVIEW QUESTIONS

ON THE SUBJECT OF

CONSTRUCTION OF BOILERS

1. If they are near together, how are two flat parallel surfaces stayed?
2. Describe a rivet.
3. Since copper is such a desirable metal for boiler work, why is it not used more extensively?
4. Why is a large factor of safety used for stays?
5. State what you can (briefly) about the injuries done to plates by punching and the methods employed to overcome them.
6. Why are not welded joints used more generally?
7. In what two ways are tubes fastened to the tube sheet?
8. About what is the ratio of length to diameter of the multitubular type of boiler?
9. Explain riveting with countersunk head.
10. Is the greatest tendency to rupture along the longitudinal or the circumferential seams?
11. Why is the length of a grate limited?
12. Which is the stronger form of riveting, the lap joint or double butt joint (both with double riveting)?
13. Why are the short screw stay bolts turned smooth in the center?
14. Why are flanged joints preferable to those made with cast-iron angle irons?
15. What is a water leg?
16. For what qualities are boiler materials tested?
17. What is the principal advantage of pneumatic calking?
18. Name some of the considerations that must be kept in mind when designing a boiler.

19. If the rivet is 1 inch in diameter what would you make the pitch, if a single-riveted lap joint?

20. Upon what does the choice of type of boiler depend?

21. What is the thickness of the shell of a boiler if the diameter is 60 inches, the steam pressure 70 pounds per square inch, the joint has an efficiency of .68, and the working strength of the metal 9,000 pounds per square inch? The working strength equals the breaking strength S, divided by f.

Use the formula $t=\frac{fDp}{2SE}$ Ans. $\frac{3}{8}$ inch

22. Find the allowable pressure, if the above conditions are the same, with the exception of t, which is $\frac{1}{2}$ inch.

Ans. 102 pounds per square inch

23. Why should calking be done carefully and with a properly shaped tool?

24. About what fraction of the volume of a multitubular boiler is the steam space?

25. If the boiler is to supply steam to a high-speed engine, should the steam space be larger or smaller than if to a low-speed engine?

26. Why is wrought iron preferable to cast iron for boiler shells?

27. Why is a riveted joint weaker than an uncut plate?

28. A boiler evaporates 3,211 pounds of water per hour. The grate is $6\frac{1}{2}$ feet by 4 feet and the coal evaporates $9\frac{1}{2}$ pounds of water per pound. What is the rate of combustion?

Ans. 13 pounds per sq. ft. per hour

29. What kind of joint is generally used for longitudinal seams?

30. Explain in your own words the meaning of the expression "equivalent evaporation from and at 212 degrees Fahrenheit".

31. Name four general requirements that a boiler must have.

32. What are the advantages of machine riveting?

33. The section of a boiler plate before testing was .88 inch by 1 inch. What was the ultimate tensile strength if the specimen broke at 56,760 pounds?

34. The 8-inch length of a test piece measured 9.96 inches after testing. What was the elongation in per cent?

REVIEW QUESTIONS

ON THE SUBJECT OF

TYPES OF BOILERS

1. Why are water-tube boilers lighter than those of the fire-tube type?

2. In the fire-tube boiler are the tubes large or small for forced draft? Why?

3. Make a sketch of a multitubular boiler and locate the important parts. Show by means of arrows the path of the hot gases.

NOTE: The sketch should combine Figs. 12 and 13.

4. Name three boilers which have curved water tubes, are non-sectional, and have a steam drum of the cross type.

5. Describe briefly the Stirling boiler.

6. Classify, under the headings "sectional" and "non-sectional", all the water-tube boilers described in this Instruction Paper.

7. Trace the changes which occurred in the development of the horizontal multitubular boiler from the plain cylindrical.

8. What is the peculiarity of Beggs' Directurn boiler?

9. What are the advantages of the double-ended return-tubular boiler?

10. Wherein do Babcock and Wilcox boilers differ from Edge Moor boilers?

11. In what way does the Niclausse boiler differ from all others herein described? Trace the course of the water. Describe the construction.

12. Describe briefly the flue boilers—Cornish, Lancashire, and Galloway. Identify each by stating its peculiarities in a few words.

13. What is a breeches-flued boiler?

14. Sketch the wagon top boiler.

15. Explain the difference between the gas travel of Babcock and Wilcox and the Heine boilers.

16. How does the Belpaire fire box differ from the Wootten?

17. Why are some vertical fire-tube boilers not economical?

18. Describe the fire-box construction in the Manning boiler?

19. Sketch longitudinal section of the Mosher boiler.

20. What boilers belong to the class that may be briefly described as a straight vertical water-tube, single-tube, non-sectional.

21. Describe the Brady boiler. Why is the furnace flue corrugated?

22. Name the boilers which have the following characteristics: *water-tube — non-sectional — straight-tube — water-tubes horizontal or nearly so—steam drum horizontal.*

23. Is the Worthington boiler sectional? Describe the arrangement of tubes and furnace.

24. Discuss briefly some of the advantages claimed for water-tube boilers.

25. Why should one of the brackets supporting a multitubular boiler be placed on rollers?

26. In general, how are flat plates within a boiler prevented from bulging or collapsing?

27. What constitutes the heating surface of a cylindrical marine boiler?

28. State reasons why water-tube boilers are better than cylindrical boilers for marine work.

29. Describe briefly the causes for loss in efficiency in the furnace of a marine boiler.

30. Where should the feed water be introduced into a cylindrical marine boiler?

REVIEW QUESTIONS

ON THE SUBJECT OF

BOILER ACCESSORIES

1. What are the defects of the lever safety valve?
2. What advantage is there to be gained by maintaining a constant water level?
3. Explain the principle on which the injector works.
4. What gain is made by the use of a feed-water heater?
5. Of what are fusible plugs made? Where are they used? Why?
6. Describe the pop safety valve.
7. Where is the best place to introduce feed water?
8. Describe the principle and action of a Bourdon gage.
9. What devices have been tried to better the circulation in the boiler?
10. What is the advantage of having try cocks on a boiler that is fitted with a good water-gage column?
11. What is an economizer?
12. What is a reducing valve?
13. How may the bottom blow-out pipe be most readily protected from burning?
14. Why is a manhole or handhole made elliptical instead of circular?
15. Explain the action of the diaphragm type of reducing valve.
16. How does a feed-water heater assist in the purification of the feed water?
17. How is a boiler set to allow for expansion?
18. What are the prime essentials in connection with the feed apparatus of a battery of boilers?

19. A lever safety valve is set to blow off at 65 pounds. The ball at the end weighs 110 pounds; the lever weighs 48 pounds, and has its center of gravity 18 inches from the fulcrum. The valve is 4½ inches from the fulcrum. The valve has a diameter of 4½ inches, and, with the spindle, weighs 14 pounds. At what distance from the fulcrum must the ball be placed?

20. What is the efficiency of an injector considered as a feed pump and as a feed-water heater combined?

21. How many and what types of valves are placed in blow-off lines?

22. What is the purpose of an automatic stop and check valve? Where is it placed?

23. Explain the principle of a centrifugal pump.

24. What two types of feed-water regulators are used?

25. What is the difference between saturated and superheated steam?

26. Why is a suspended horizontal tubular boiler better than one resting on lugs?

REVIEW QUESTIONS

ON THE SUBJECT OF

BOILER PRACTICE

1. What is the unit of boiler horsepower?

2. When is a "herringbone" grate used?

3. State several reasons why the efficiency of a boiler and grate is less than 100 per cent.

4. What harm comes from admitting engine oil to the boiler?

5. What is the most satisfactory pipe covering in your estimation, and why?

6. Why is boiler scale undesirable?

7. If you were in charge of a boiler and the water gage gave no indication of water, what would you do?

8. What precautions should a fireman take before getting up steam?

9. Explain the three methods of hand firing.

10. What data should be taken at a boiler trial, and at what intervals?

11. Name some general causes for boiler explosions.

12. Name three ways to prevent and remove scale.

13. What is the procedure for boiler testing by the Standard method?

14. What is the source of the energy developed in the explosion of a boiler? Explain fully.

15. Name the principal apparatus used in boiler trials, and describe their uses.

16. What impurities in feed water cause corrosion?

17. Explain the action of soda on feed-water impurities.

18. The following results were obtained from a separator calorimeter test: Weight of dry steam, 12 pounds; weight of water,

separated, 8 ounces; radiation loss, 2 ounces. Find the quality of the steam.

19. The data from a throttling calorimeter test are as follows: Steam pressure, 85 pounds (absolute); pressure in calorimeter, 25 pounds (absolute); and temperature in calorimeter, 266.5° F. Find the quality of the steam.

20. Explain fully in simple language the meaning of the expression "equivalent evaporation from and at 212° F."

21. Find the equivalent evaporation when a boiler evaporates 1,900 pounds of water per hour, the gage pressure being 115 pounds, and the temperature of feed water 80° F. What is the horsepower of the boiler?

22. What is grooving, and what is the cause?

23. What precautions should be taken in blowing out a boiler.

24. What is meant by draft? What causes natural draft?

25. Name four kinds of mechanical stokers, all of different form, and explain their characteristics.

26. Give the natural or chemical reason why smoke is created by badly-designed boiler installations.

27. Work out the heat value of a boiler horsepower hour from the steam-table figures. Show computations.

28. What is a turbine tube cleaner?

29. Give advantages of oil as a fuel. Discuss methods of use briefly.

30. Describe boiler tube-stopper which can be used without drawing its fire.

REVIEW QUESTIONS

ON THE SUBJECT OF

PUMPS

1. Find the pressure per square inch corresponding to a head of water of 187.42 feet.

2. Under what conditions should a centrifugal pump be used?

3. Describe the rotary pump.

4. If a large quantity of water is to be lifted a slight amount—for instance, 20 feet—is it better to use a direct-acting pump or a centrifugal pump?

5. How many gallons per minute can be raised by a pump having a water cylinder 8 inches in diameter and 12 inches stroke, if it makes 45 double strokes per minute? Assume 6% slip.

6. What materials are used for valve disks for cold water? For hot water?

7. Which is the better form of spring for a valve, *cylindrical* or *conical?* Why?

8. Under what conditions is it better to use a plunger pump rather than the piston type?

9. A 12″×10″ duplex makes 52 double strokes per minute. What is the piston speed in feet per minute and what is the discharge in gallons?

10. A double-acting pump is to discharge 232 gallons per minute. On account of the pressure against which the pump must work, the water cylinder must be 7 inches in diameter. The allowable number of double strokes per minute is 55. What is the length of stroke? What is the piston speed?

11. Suppose a pump has a suction of 14 feet and the loss due to friction in the piping is 3 pounds per square inch. The pump is a

3″ × 10″ and the discharge is against a head of 86 feet. If the pump makes 40 double strokes per minute, what horse-power is required, allowing 20% for friction?

12. The head against which a pump works is 122 feet. If the plunger is 4 inches in diameter and the steam end 7 inches, what steam pressure must be used? Consider the plunger friction to be 75 pounds.

13. A boiler-feed pump works against a pressure of 145 pounds. It draws water from a tank located so that the lift is 16 feet. If the steam pressure at the pump is 130 pounds and the steam cylinder is 8 inches in diameter, what is the diameter of the plunger? (a) Make no allowance for friction. (b) Assume friction to be 15%.

14. Describe the setting of the valves of a duplex pump.

15. Describe the valve motion of a duplex pump.

16. Draw a diagram and locate the high-pressure cylinder, the low-pressure cylinder, the pistons, the piston rod, water cylinder, plunger, and air chamber of a tandem compound pump.

17. What means are used for connecting the shaft of a gas or steam engine to a triplex pump?

18. How is steam cushion obtained in a pump?

19. Why are laps added to steam valves?

20. What should be the maximum lift for a disk valve?

21. Explain with sketch the action of the combined forcing and lifting pump (double-acting).

22. Describe the usual lost-motion device for a duplex pump. Why is it used?

23. Where should the check valve of a suction end be placed?

24. What kind of packing is commonly used in the water-end stuffing-box?

25. If a pump slams on one stroke but not on the other, what is the probable cause?

26. Give method of procedure in starting a compound condensing pump.

27. What is the most common cause of short stroke on one side of a duplex pump?

28. What is meant by *duty*?

29. How may the slip be found?

30. What size rod would you use for a 9″ piston?

INDEX

INDEX

The page numbers of this volume will be found at the bottom of the pages; the numbers at the top refer only to the section.

Page
Air-lift pumps 435
Alarm systems 179
Almy marine boiler 152
Angle valve 185
Annealing 26
Ash-handling apparatus 252
  pneumatic system 252
  steam jet system 253
Automatic control of pumps 438
Automatic skimmer systems 219
Automatic stop and check valves 193

B

B-valve 442
Babcock and Wilcox boiler 113
Babcock and Wilcox marine boiler 149
Ball valves 399
Barr strainer 463
Barrel calorimeter 347
Belpaire boiler 101
Belt-driven pumps 425
Bigelow-Hornsby boiler 136
Blake pump valve 447
Blow-off cocks 191
Blow-off pipe 72
Blow-off valve 192
Boiler accessories 71, 169–255
  ash-handling apparatus 252
  blow-off pipe 72
  brackets 72
  breechings 72, 246
  chimneys 72, 238
  coal-handling apparatus 249
  columns 72
  damper 72
  draft apparatus 237
  feed apparatus 200
  feed pump 71

Page
Boiler accessories (continued)
  fuel economizers 247
  furnace fittings 72
  fusible plugs 72, 174
  gage cocks 71
  gage glasses 180
  handholes 72, 169
  heaters 72
  high- and low-water alarms 72
  injector 71, 207
  lagging 233
  lugs 72
  manholes 72, 169
  masonry 72
  pressure gage 72
  pumps 205
  safety valve 72
  soot blowers 230
  steam gages 176
  steam piping 72, 196
  steam separators 224
  superheaters 220
  supports 172
  tools 72
  traps 227
  try cocks 182
  valves 183
  water columns 179
  water gage 71
Boiler action, essential principles of 11
Boiler circulation 155
Boiler cleaning 160
Boiler construction 11–68
  allowable pressure 66
  area of grate 62
  calking 35
  expanding tubes, methods of 57
  flanging 29

Page

- Boiler construction (continued)
  - flues 52
  - furnace flues 59, 67
  - heating surface 65
  - manholes 43
  - materials 12
  - plates and joints, arrangement of 37
  - rating 63
  - requirements 60
  - riveted joints 25, 30
  - sections 67
  - shaping butt straps 29
  - stays 44
  - steam space 64
  - tubes 52
  - water-leg construction 38
  - welded joints 36
- Boiler coverings 236
- Boiler design 155
  - accessibility 160
    - provisions usual for inspection and cleaning 160
    - replacement of tubes 161
  - circulation 155
    - auxiliary pipes 157
    - effectiveness of heating surfaces 158
    - fire-tube boilers 155
    - importance of good circulation 157
    - water-tube boilers 156
  - plant features influencing design 163
    - available space 165
    - fuel 164
    - personal element 163
    - size of plant 163
    - stokers 164
    - water 164
  - shapes and sizes of tubes 162
    - straight vs. bent tubes 162
    - tube diameters 162
- Boiler explosions 328
  - boiler inspection 329
  - causes 331
  - energy developed 330
  - investigation 334
  - nature of 329
  - prevention 335

Page

- Boiler functions 71
- Boiler inspection 67, 160, 329
- Boiler materials 12
  - brass 14
  - bronze 14
  - cast iron 12
  - copper 14
  - steel 13
  - tests of 14
    - diagrams 16
    - elastic limit 15
    - elongation 15
    - reduction of area 15
    - rules of American Society of Mechanical Engineers 18
    - standard regulations 18
    - strain 15
    - stress 14
    - stretch limit 15
    - testing machines 17
    - ultimate strength 15
  - wrought iron 12
- Boiler practice 257–365
- Boiler settings 257
  - foundation 258
  - furnace walls 259
  - iron supports 258
- Boiler supports 172
  - bracket 173
  - suspension 173
- Boiler test code, abstract of 358
- Boiler tests 355
- Boiler tubes 52
  - holes and ends 56
  - methods of expanding 57
    - Dudgeon 58
    - Prosser 57
  - spacing 52
  - stay 58
  - types 57
- Boiler types 71–166
  - classification 73
  - early forms 75
  - fire-box 75, 99
  - fire-tube 75, 84, 155
  - internally-fired marine 92
  - marine 144

Note.—For page numbers see foot of pages.

Page
Boiler types (continued)
  modern flue boilers 79
  peculiar forms 104, 142
  water-tube 75, 109, 156
Boilers, care of 316
  pressure apparatus 316
  setting and attachments 318
Bottom blow-out 218
Bourdon dial gage 176
Brady Scotch boiler 106
Brass 14
Breechings 72, 246
Bronze 14

C

Cahall boiler 131
Calking 35
  proper method 35
  tools 35
Calorimeters 347
  barrel 347
  separating 351
  throttling 352
Cameron steam valve 444
Cast iron 12
Centrifugal pumps 208, 380
  characteristics 387
  curve of the blades an involute 381
  operation 388
  speed 383
  staying 386
  turbine 386
  types 384
  volute 385
  whirlpool 384
Check valve 186, 462
Chimneys 238
  construction 240
  Kent's formula 239
Coal-handling apparatus 249
  chutes 251
  storage bins 251
Cochrane boiler 105
Combined-condenser pumps 427
Compound steam pump valves 451
Compressed-air pumps 431
Connelly boiler 138

Page
Construction of boilers 11–68
Copper 14
Cornish boiler 79
Corrosion 319
  external 319
  internal 320
    grooving 321
    pitting 320
    prevention 321
Cylindrical boilers 77
  marine 147

D

D-valve 440
Damper frame and damper 72
Davidson pump valve 448
Dean Brothers steam valve 446
Deane of Holyoke steam valve 446
Direct-acting pumps 423
Directurn boilers 108
Double-ended boiler 95, 147
Double-tube boiler, definition of 75
Draft gages 305, 450
Drafts, natural and forced 237
  closed ash pit 242
  closed stokehold 242
  Ellis and Eaves system 244
  Howden system 243
  induced draft 243
  steam jets 244
Dry-vacuum pumps 429
Dudgeon expander 58
Duplex pump valve 450
Duplex pumps 417
Duty of pump 472

E

Edge Moor boiler 119
Efficiency meter 307
Ellis and Eaves system of forced draft 244
Erie City boiler 139
Evaporative test for boilers, data and results 364
Evaporators 213
Expanders 57
Explosions, cause of 331
Externally-fired boiler, definition of 75

Note.—For page numbers see foot of pages.

Page

F

- Feed apparatus 200
  - bottom blow-out 218
  - circulating apparatus 210
  - evaporators 213
  - feed-water heaters 214
  - feed-water regulators 211
  - injectors 207
  - pumps 205
  - skimmers 217
  - strainers 220
- Feed pump 71
- Feed-water connections 201
- Feed-water heaters 214
- Feed-water regulators 211
- Fire-box boiler 75, 99
  - definition of 75
- Fire pumps 418
- Fire-tube boilers 75, 84, 155
  - circulation in 155
  - definition of 75
  - fire-box 75, 99
    - Belpaire 101
    - Lentz 103
    - locomotive 99
    - stationary 104
    - Wootten 103
  - horizontal 84
    - multitubular 84
    - single-flue 84
  - internally-fired marine 92
    - return-tubular 92
    - through-tube 99
  - peculiar forms 104
    - Brady 106
    - Cochrane 105
    - Directurn 108
    - Shapley 105
  - vertical 88
    - Manning 90
    - multitubular 89
    - single-tube 88
- Firing by hand 268
- Flanging 29
- Flexible valves 396
- Fuel available, influence on boiler design 164

Page

- Fuel burning, general features of 289
- Fuel economizers 247
  - Green 247
  - Sturtevant 248
- Fuels, heat value of 337
  - artificial fuels 342
  - bagasse 341
  - charcoal 340
  - coal 337
  - coke 340
  - culm 340
  - gas 342
  - lignite 339
  - liquid fuels 341
  - peat 339
  - pulverized coal 343
  - straw 341
  - wood 340
- Furnace fittings 72
- Furnace flues 59, 67
- Furnaces 261, 289
  - doors 263
  - down draft 274
  - grate 263
  - gravity feed 275, 291
  - hand-fired 261
  - oil-burning 276
  - semi-automatic 273
- Fusible plugs 174

G

- Gage cocks 71
- Gage glasses 180
- Galloway boiler 82
- Gasketed joints 199
- Gate valve 185
- Globe valve 184
- Grate area for boilers 62
- Grates 263
  - dumping devices 267
  - forced draft 267
  - hand-fired 263
  - rocking 265
- Green fuel economizer 247
- Gunboat boiler 147

H

- Handholes 44, 72, 169
- Harrison boiler 143

Note.—For page numbers see foot of pages.

Page
Haystack boiler 75
Hazelton boiler 142
Heater 72
Heating surface of boilers 65
Heine boiler 121
High- and low-water alarms 72
Hinged valves 397
Horizontal fire-tube boilers 84
Horizontal water-tube boilers 113
Horsepower of boilers 61, 344
Howden system of forced draft 243
Hydraulic ram 373

I

Inclined-grate stokers 279, 296
Incrustation 324
Injectors 71, 207
Instruments, boiler room 304
Integrating meter 312
Internally-fired boiler, definition of 75
Internally-fired marine boiler 92

J

Jet pumps 376
Joints in boilers 37

K

Kent's formula 239
Knowles steam valve 442

L

Lagging 233
  boiler covering 236
  pipe covering 234
Lancashire boiler 81
Launch boilers 155
Lentz boiler 103
Lever safety valve 187
Locomotive boilers 99, 147
Lubrication of pumps 467
Lugs or brackets 72

M

Manholes 43, 72, 169
  frame construction 43
  location 43
  size of opening 43

Page
Manning boiler 90
Marine boilers 144
  cylindrical 147
    double-ended Scotch 147
    gunboat 147
    locomotive 147
    single-ended 147
  rectangular 145
    wet- and dry-bottom 146
  water-tube 147
    Almy 152
    Babcock and Wilcox 149
    comparison with cylindrical 147, 154
    launch 155
    standard, for U.S. wooden steamships 150
    variations from standard land types 154
Masonry 72
Mechanical draft 242
Mechanical stokers 277, 289
  inclined grate 279, 296
  manipulation of 289
  traveling grate 279, 292
  underfeed 283, 299
Modern flue boilers 79
  Cornish 79
  Galloway 82
  Lancashire 81
Mosher boiler 122
Motor-driven pumps 425
Multitubular boilers 84, 89

N

Nagle valve 400
Niclausse boiler 126
Non-sectional boiler, definition of 75

O

Operating troubles of pumps 467
Orsat flue gas analyzing apparatus 308

P

Pipe coverings 234
Piping of pumps 462

Note.—For page numbers see foot of pages.

Page
Piping of pumps (continued)
  check valves 462
  duplicate system 462
  sizes of pipe 464
  strainer 463
Plant economy vs. boiler economy 301
Plates and joints, arrangement of 37
Plugs, fusible 174
Pop safety valve 189
Poppet valves 398
Porcupine boiler 142
Pressure apparatus 316
Pressure of boilers 66
Pressure gage 72
Priming 224
Prosser expander 57
Pump valves 395
  ball 399
  flexible 396
  hinged 397
  Nagle 400
  poppet 398
Pumps 205, 367–479
  automatic control 438
  care 466
  centrifugal 380
  classification 375
  design and construction 401
  erection of 460
  forcing 371
  hydraulic ram 373
  jet 376
  lifting 370
  lubrication 467
  operating troubles 469
  packing 467
  piping 462
  principles of action 367
  reciprocating 389
  rotary 378
  setting of valves 457
  steam valves 440
  testing 472
  types 415
    air-lift 435
    belt-driven 425
    combined-condenser 427

Page
Pumps (continued)
  types
    compressed air 431
    direct-acting 423
    dry vacuum 429
    duplex 417
    motor-driven 425
    single 415
    triplex 421
    turbine-driven 425
  valves 395, 401, 440, 468
Pyrometers 308

R

Rating of boilers 63
Reamed holes 26
Reciprocating pumps 205, 389
  air chamber 404
  arrangement of parts 408
  bucket 402
  cylinder 401
  design and construction 401
  forcing 391
  frames 407
  lifting 389
  packing 403
  piston 402
  plunger 404
  ports 406
  proportion of parts 409
  pump ends 407
  stuffing box 406
  types 415
  valves 395, 401
Rectangular marine boilers 145
Reducing valves 194
Return traps 229
Return-tubular boilers 92
Return-tubular fire-box boiler 104
Riedler system of mechanically operated valves 438
Riveted joints in boilers 25
  annealing 26
  butt straps 29
  efficiency 30
  flanging 29
  reamed holes 26

Note.—For page numbers see foot of pages.

Page

- Riveted joints in boilers (continued)
  - rivet holes, drilled 25
  - rivet holes, punched 25
  - types of 30
    - butt 32
    - lap 31
- Rivets, forms of 27
- Rivets, methods of driving 28
- Root boiler 116
- Rotary pumps 378
- Rust boiler 135

S

- Safety valve 72, 187
- Scale formation 324
  - causes 324
    - carbonate of lime 325
    - carbonate of magnesia 326
    - iron salts 326
    - oil 324
    - sulphate of lime 325
  - prevention 326
    - blow-out apparatus 327
    - boiler compounds 328
    - chemical precipitation 326
    - contraction and expansion 327
    - electrolytic action 328
    - removal by hand 326
    - turbine tube cleaners 326
- Sectional boiler, definition of 75
- Sections of boiler 67
- Separating calorimeter 351
- Shapley boiler 105
- Shop equipment 25
- Single-ended boiler 93, 95, 147
- Single-flue boiler 84, 93
- Single pumps 415
- Single-tube boiler 88
  - definition of 75
- Skimmers 217
- Smoke indicators and recorders 311
- Smoke prevention 335
  - municipal regulations 337
  - preventive devices 336
- Soot blowers 230
- Standard marine boiler 150
- Stationary boilers 104

Page

- Stationary return-tubular boiler 97
- Stay bolts 47
- Stay rods 45
- Stays 44
  - area to be stayed 52
  - crown sheet supports 48
  - diagonal 46
  - gusset 46
  - load on stay bolts 52
  - riveted stay bolts 47
  - stay rod 45
  - stiffening angles 48
- Steam and auxiliaries 220
- Steam dome 225
- Steam-flow meters 315
- Steam gages 176
- Steam jets 244
- Steam piping 72, 196
- Steam separators 224
- Steam space of boilers 64
- Steam traps 227
- Steam valves 440
- Steel 13
- Stirling boiler 133
- Stokers, mechanical 164, 277
- Strainers 220, 463
- Sturtevant fuel economizer 248
- Superheaters 220

T

- Tables
  - air chamber, dimensions of 405
  - air-lift pumps, constants for 434
  - air-lift pumps, well pipe sizes for 435
  - ball valves, spring wire sizes for 400
  - bare pipe data 234
  - barometer readings 368
  - coals, analyses and heat value of 338
  - compound pump data 457
  - double-riveted joints, efficiencies of 34
  - evaporation, factors of 346
  - fire pumps, dimensions and capacities of 420
  - flexible valve data 397
  - friction of water in pipes 466
  - gases, evaporative power of 342

Page

Tables (continued)
  hinged valve data 397
  hydraulic ram data 375
  lap-welded boiler tubes, dimensions of 56
  lift and inlet head of various temperatures of water 370
  maximum capacities of pumps for boiler feeding 419
  pipe sizes, suction and delivery 464
  piston rods, sizes of 403
  pumps, capacity of 410
  radiation of heat, relative value of preventive 235
  riveted lap joints, proportions of 32
  rivets, dimensions of 28
  saturated steam, properties of 348, 349
  slip, allowance for 411
  stack sizes by Kent's formula 241
  stay bolts with V-threads, allowable loads 51, 52
  stays and stay bolts, maximum allowable stress 51
  steel, chemical composition of 13
  triplex single-acting power pumps, data for 422
  water pressure under different heads 374
Testing boiler steel, rules for 18
Testing machines 17
Testing pumps 472
Thermometers 308
Thornycroft-Marshall boiler 125
Throttling calorimeter 352
Through-tube boilers 99, 147
Tools 72
Traps 227
Traveling-grate stokers 279, 292
Triplex pumps 421
Troubles of pumps 469
  short stroke 471
  slamming 469
  slicking 470
  starting 470
  stopping 471
Try cocks 182
Tube stoppers 323

Page

Tubes of boilers 52, 161
  replacement of 161
  shapes and sizes of 162
Turbine-driven pumps 425
Turbine-tube cleaner 326
Types of boilers 71–166

U

Underfeed stokers 283, 299

V

V-notch meter 313
Valves 183, 395, 401, 440, 468
  automatically operated 187
    automatic stop and check 193
    blow-off 192
    pop safety 189
    reducing 194
    safety 187
  manually operated 184
    angle 185
    check 186
    gate 185
    globe 184
    materials 186
Venturi meter 313
Vertical fire-tube boilers 88
Vertical water-tube boilers 130

W

Wagon boiler 76
Water available, influence on boiler design 164
Water columns 179
Water-end auxiliaries 200
Water evaporation per pound of fuel 63
Water gage 71
Water-leg construction 38
Water-tube boilers 75, 109, 156, 261
  advantages 110
  circulation in 156
  horizontal 113
    Babcock and Wilcox 113
    Edge Moor 119

Note.—For page numbers see foot of pages.

Page
Water-tube boilers (continued)
  horizontal
    Heine 121
    Mosher 122
    Niclausse 126
    Root 116
    Thornycroft-Marshall 125
    Worthington 119
  peculiar forms 142
    Harrison 143
    Hazelton or Porcupine 142
  vertical 130
    Bigelow-Hornsby 136
    Cahall 131

Page
Water-tube boilers (continued)
  vertical
    Connelly 138
    Erie City 139
    Rust 135
    Stirling 133
    Wickes 130
Water-tube marine boilers 147
Welded joints 36
Wet- and dry-bottom boilers 146
Wickes boiler 130
Wootten boiler 103
Worthington boiler 119
Wrought iron 12

Note.—For page numbers see foot of pages.

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